Instructor's Manual

to accompany

Electronic Principles

Seventh Edition

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Higher Education

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Preface

To best serve the needs of the instructor, the solutions or answers for the problems contained in the Malvino/Bates student text and experiments manual have been combined in this single volume. This instructor's manual has been designed to provide you, the instructor, with a convenient reference source for answers to both even- and odd- numbered exercises.

The sections of the *Instructor's Manual for Electronic Principles,* Seventh Edition, are as follows:

1. Solutions to problems in *Electronic Principles,* Seventh Edition. Here you will find solutions for all the questions and problems at the end of the textbook chapters. In most cases, complete worked-out solutions are provided for your convenience.
2. Answers for the experiments manual. This part contains representative data for all experiments. Also included are the answers to the questions at the end of each experiment.
3. Transparency masters. Included in this section are 33 figures from the student text, along with manufacturers' data sheets for popular devices for use as transparency masters or for duplication for student use.

Albert Paul Malvino
David J. Bates

Part 1

Electronic Principles Seventh Edition

Chapter 1 Introduction

SELF-TEST

1. a	**7. b**	**13. c**	**19. b**
2. c	**8. c**	**14. d**	**20. c**
3. a	**9. b**	**15. b**	**21. b**
4. b	**10. a**	**16. b**	**22. b**
5. d	**11. a**	**17. a**	**23. c**
6. d	**12. a**	**18. b**	

JOB INTERVIEW QUESTIONS

Note: The text and illustrations cover many of the job interview questions in detail. An answer is given to job interview questions only when the text has insufficient information.

2. It depends on how accurate your calculations need to be. If an accuracy of 1 percent is adequate, you should include the source resistance whenever it is greater than 1 percent of the load resistance.

5. Measure the open-load voltage to get the Thevenin voltage V_{TH}. To get the Thevenin resistance, reduce all sources to zero and measure the resistance between the *AB* terminals to get R_{TH}. If this is not possible, measure the voltage V_L across a load resistor and calculate the load current I_L. Then divide $V_{TH} - V_L$ by I_L to get R_{TH}.

6. The advantage of a 50 Ω voltage source over a 600 Ω voltage source is the ability to be a stiff voltage source to a lower value resistance load. The load must be 100 greater than the internal resistance in order for the voltage source to be considered stiff.

7. The expression *cold-cranking amperes* refers to the amount of current a car battery can deliver in freezing weather when it is needed most. What limits actual current is the Thevenin resistance caused by chemical and physical parameters inside the battery, not to mention the quality of the connections outside.

8. It means that the load resistance is not large compared to the Thevenin resistance, so that a large load current exists.

9. Ideal. Because troubles usually produce large changes in voltage and current, so that the ideal approximation is adequate for most troubles.

10. You should infer nothing from a reading that is only 5 percent from the ideal value. Actual circuit troubles will usually cause large changes in circuit voltages. Small changes can result from component variations that are still within the allowable tolerance.

11. Either may be able to simplify the analysis, save time when calculating load current for several load resistances, and give us more insight into how changes in load resistance affect the load voltage.

12. It is usually easy to measure open-circuit voltage and shorted-load current. By using a load resistor and measuring voltage under load, it is easy to calculate the Thevenin or Norton resistance.

PROBLEMS

1-1. *Given:*

$V = 12$ V
$R_S = 0.1\ \Omega$

Solution:

$R_L = 100R_S$
$R_L = 100(0.1\ \Omega)$
$R_L = 10\ \Omega$

Answer: The voltage source will appear stiff for values of load resistance of $\geq 10\ \Omega$.

1-2. *Given:*

$R_{L\min} = 270\ \Omega$
$R_{L\max} = 100\ \text{k}\Omega$

Solution:

$R_S < 0.01\ R_L$ (Eq. 1-1)
$R_S < 0.01(270\ \Omega)$
$R_S < 2.7\ \Omega$

Answer: The largest internal resistance the source can have is 2.7 Ω.

1-3. *Given:* $R_S = 50\ \Omega$

Solution:

$R_L = 100R_S$
$R_L = 100(50\ \Omega)$
$R_L = 5\ \text{k}\Omega$

Answer: The function generator will appear stiff for values of load resistance of $\geq 5\ \text{k}\Omega$.

1-4. *Given:* $R_S = 0.04\ \Omega$

Solution:

$R_L = 100R_S$
$R_L = 100(0.04\ \Omega)$
$R_L = 4\ \Omega$

Answer: The car battery will appear stiff for values of load resistance of $\geq 4\ \Omega$.

1-5. *Given:*

$R_S = 0.05\ \Omega$
$I = 2$ A

Solution:

$V = IR$ (Ohm's law)
$V = (2\text{ A})(0.05\ \Omega)$
$V = 0.1$ V

Answer: The voltage drop across the internal resistance is 0.1 V.

1-6. *Given:*

$V = 9$ V
$R_S = 0.4\ \Omega$

Solution:

$I = V/R$ (Ohm's law)
$I = (9\text{ V})/(0.4\ \Omega)$
$I = 22.5$ A

Answer: The load current is 22.5 A.

1-7. *Given:*

$I_S = 10$ mA
$R_S = 10\text{ M}\Omega$

Solution:

$R_L = 0.01\ R_S$
$R_L = 0.01(10\text{ M}\Omega)$
$R_L = 100\text{ k}\Omega$

Answer: The current source will appear stiff for load resistance of $\leq 100\text{ k}\Omega$.

1-8. *Given:*

$R_{L\min} = 270\ \Omega$
$R_{L\max} = 100\text{ k}\Omega$

Solution:

$R_S > 100\ R_L$ (Eq. 1-3)
$R_S > 100(100\text{ k}\Omega)$
$R_S > 10\text{ M}\Omega$

Answer: The internal resistance of the source is greater than 10 MΩ.

1-9. *Given:* $R_S = 100\text{ k}\Omega$

Solution:

$R_L = 0.01R_S$ (Eq. 1-4)
$R_L = 0.01(100\text{ k}\Omega)$
$R_L = 1\text{ k}\Omega$

Answer: The maximum load resistance for the current source to appear stiff is 1 kΩ.

1-10. *Given:*

$I_S = 20$ mA
$R_S = 200\text{ k}\Omega$
$R_L = 0\ \Omega$

Solution:

$R_L = 0.01R_S$
$R_L = 0.01(200\text{ k}\Omega)$
$R_L = 2\text{ k}\Omega$

Answer: Since 0 Ω is less than the maximum load resistance of 2 kΩ, the current source appears stiff; thus the current is 20 mA.

1-11. *Given:*

$I = 5$ mA
$R_S = 250\text{ k}\Omega$
$R_L = 10\text{ k}\Omega$

Solution:

$R_L = 0.01R_S$ (Eq. 1-4)
$R_L = 0.01(250\text{ k}\Omega)$
$R_L = 2.5\text{ k}\Omega$

$I_L = I_T(R_S)/(R_S + R_L)]$ (Current divider formula)
$I_L = 5\text{ mA}[(250\text{ k}\Omega)/(250\text{ k}\Omega/(250\text{ k}\Omega + 10\text{ k}\Omega)]$
$I_L = 4.80$ mA

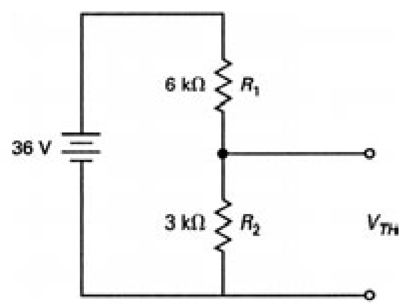
Answer: The load current is 4.80 mA, and, no, the current source is not stiff since the load resistance is not less than or equal to 2.5 kΩ.

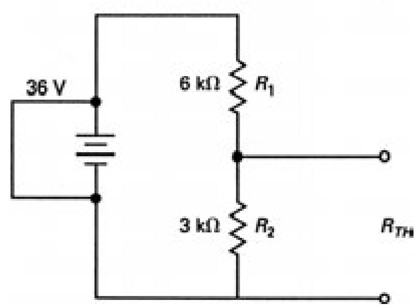
1-12. *Solution:*

$V_{TH} = V_{R2}$
$V_{R2} = V_S[(R_2)/(R_1 + R_2)]$ (Voltage divider formula)
$V_{R2} = 36\text{ V}[(3\text{ k}\Omega)/(6\text{ k}\Omega + 3\text{ k}\Omega)]$
$V_{R2} = 12$ V

$R_{TH} = [R_1R_2/R_1 + R_2]$ (Parallel resistance formula)
$R_{TH} = [(6\text{ k}\Omega)(3\text{ k}\Omega)/(6\text{ k}\Omega + 3\text{ k}\Omega)]$
$R_{TH} = 2\text{ k}\Omega$

Answer: The Thevenin voltage is 12 V, and the Thevenin resistance is 2 kΩ.





(*a*) Circuit for finding V_{TH} in Prob. 1-12. (*b*) Circuit for finding R_{TH} in Prob. 1-12.

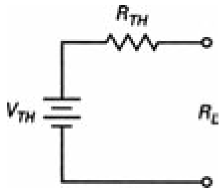
1-13. *Given:*

$V_{TH} = 12$ V
$R_{TH} = 2\text{ k}\Omega$

Solution:

$I = V/R$ (Ohm's law)
$I = V_{TH}/(R_{TH} + R_L)$
$I_{0\Omega} = 12\text{ V}/(2\text{ k}\Omega + 0\ \Omega) = 6$ mA
$I_{1\text{k}\Omega} = 12\text{ V}/(2\text{ k}\Omega + 1\text{ k}\Omega) = 4$ mA
$I_{2\text{k}\Omega} = 12\text{ V}/(2\text{ k}\Omega + 2\text{ k}\Omega) = 3$ mA
$I_{3\text{k}\Omega} = 12\text{ V}/(2\text{ k}\Omega + 3\text{ k}\Omega) = 2.4$ mA
$I_{4\text{k}\Omega} = 12\text{ V}/(2\text{ k}\Omega + 4\text{ k}\Omega) = 2$ mA
$I_{5\text{k}\Omega} = 12\text{ V}/(2\text{ k}\Omega + 5\text{ k}\Omega) = 1.7$ mA
$I_{6\text{k}\Omega} = 12\text{ V}/(2\text{ k}\Omega + 6\text{ k}\Omega) = 1.5$ mA

Answers: 0 Ω 6 mA; 1 kΩ, 4 mA; 2 kΩ, 3mA; 3 kΩ, 2.4 mA; 4 kΩ, 2 mA; 5 kΩ, 1.7 mA; 6 kΩ, 1.5 mA.



Thevenin equivalent circuit for Prob. 1-13.

1-14. *Given:*

$V_S = 18$ V
$R_1 = 6$ kΩ
$R_2 = 3$ kΩ

Solution:

$V_{TH} = V_{R2}$
$V_{R2} = V_S[(R_2)/(R_1 + R_2)]$ (Voltage divider formula)
$V_{R2} = 18$ V[(3 kΩ)/(6 kΩ + 3 kΩ)]
$V_{R2} = 6$ V

$R_{TH} = [(R_1 \times R_2)/(R_1 + R_2)]$ (Parallel resistance formula)
$R_{TH} = [(6$ kΩ × 3 kΩ)/(6 kΩ + 3 kΩ)]
$R_{TH} = 2$ kΩ

Answer: The Thevenin voltage decreases to 6V, and the Thevenin resistance is unchanged.

1-15. *Given:*

$V_S = 36$ V
$R_1 = 12$ kΩ
$R_2 = 6$ kΩ

Solution:

$V_{TH} = V_{R2}$
$V_{R2} = V_S[(R_2)/(R_1 + R_2)]$ (Voltage divider formula)
$V_{R2} = 36$ V[(6 kΩ)/(12 kΩ + 6 kΩ)]
$V_{R2} = 12$ V

$R_{TH} = [(R_1R_2)/(R_1 + R_2)]$ (Parallel resistance formula)
$R_{TH} = [(12$ kΩ)(6 kΩ)/(12 kΩ + 6 kΩ)]
$R_{TH} = 4$ kΩ

Answer: The Thevenin voltage is unchanged, and the Thevenin resistance doubles.

1-16. *Given:*

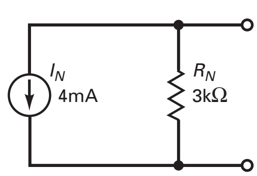
$V_{TH} = 12$ V
$R_{TH} = 3$ kΩ

Solution:

$R_N = R_{TH}$
$R_N = 3$ kΩ

$I_N = V_{TH}/R_{TH}$
$I_N = 15$ V/3 kΩ
$I_N = 4$ mA

Answer: $I_N = 4$ mA, and $R_N = 3$ kΩ



Norton circuit for Prob. 1-16.

1-17. *Given:*

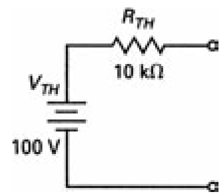
$I_N = 10$ mA
$R_N = 10$ kΩ

Solution:

$R_N = R_{TH}$ (Eq. 1-10)
$R_{TH} = 10$ kΩ

$I_N = V_{TH}/R_{TH}$ *(Eq. 1-12)*
$V_{TH} = I_NR_N$
$V_{TH} = (10$ mA)(10 kΩ)
$V_{TH} = 100$ V

Answer: $R_{TH} = 10$ kΩ, and $V_{TH} = 100$ V



Thevenin circuit for Prob. 1-17.

1-18. *Given (from Prob. 1-12):*

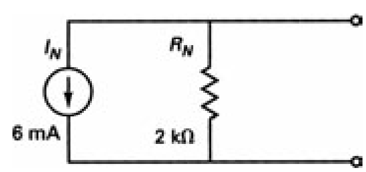
$V_{TH} = 12$ V
$R_{TH} = 2$ kΩ

Solution:

$R_N = R_{TH}$ (Eq. 1-10)
$R_N = 2$ kΩ

$I_N = V_{TH}/R_{TH}$ (Eq. 1-12)
$I_N = 12$ V/2 kΩ
$I_N = 6$ mA

Answer: $R_N = 2$ kΩ, and $I_N = 6$ mA



Norton circuit for Prob. 1-18.

1-19. Shorted, which would cause load resistor to be connected across the voltage source seeing all of the voltage.

1-20. **a.** R_1 is open, preventing any of the voltage from reaching the load resistor. **b.** R_2 is shorted, making its voltage drop zero. Since the load resistor is in parallel with R_2, its voltage drop would also be zero.

1-21. The battery or interconnecting wiring.

1-22. $R_{TH} = 2$ kΩ

Solution:

$R_{Meter} = 100R_{TH}$
$R_{Meter} = 100(2$ kΩ)
$R_{Meter} = 200$ kΩ

Answer: The meter will not load down the circuit if the meter impedance is ≥ 200 kΩ.

CRITICAL THINKING

1-23. *Given:*

$V_S = 12$ V
$I_S = 150$ A

Solution:

$R_S = (V_S)/(I_S)$
$R_S = (12$ V)/(150 A)
$R_S = 80$ mΩ

Answer: If an ideal 12 V voltage source is shorted and provides 150 A, the internal resistance is 80 mΩ.

1-24. *Given:*

$V_S = 10$ V
$V_L = 9$ V
$R_L = 75\ \Omega$

Solution:

$V_S = V_{RS} + V_L$ (Kirchhoff's law)
$V_{RS} = V_S - V_L$
$V_{RS} = 10\text{ V} - 9\text{ V}$
$V_{RS} = 1$ V

$I_{RS} = I_L = V_L/R_L$ (Ohm's law)
$I_{RS} = 9\text{ V}/75\ \Omega$
$I_{RS} = 120$ mA

$R_S = V_{RS}/I_{RS}$ (Ohm's law)
$R_S = 8.33\ \Omega$

$R_S < 0.01\ R_L$ (Eq. 1-1)
$8.33\ \Omega < 0.01(75\ \Omega)$
$8.33\ \Omega \not< 0.75\ \Omega$

Answer: **a.** The internal resistance (R_S) is 8.33 Ω. **b.** The source is not stiff since $R_S \not< 0.01\ R_L$.

1-25. *Answer:* Disconnect the resistor and measure the voltage.

1-26. *Answer:* Disconnect the load resistor, turn the internal voltage and current sources to zero, and measure the resistance.

1-27. *Answer:* Thevenin's theorem makes it much easier to solve problems where there could be many values of a resistor.

1-28. *Answer:* To find the Thevenin voltage, disconnect the load resistor and measure the voltage. To find the Thevenin resistance, disconnect the battery and the load resistor, short the battery terminals, and measure the resistance at the load terminals.

1-29. *Given:*

$R_L = 1$ kΩ
$I = 1$ mA

Solution:

$R_S > 100R_L$
$R_S > 100(1\text{ k}\Omega)$
$R_L > 100$ kΩ

$V = IR$
$V = (1\text{ mA})(100\text{ k}\Omega)$
$V = 100$ V

Answer: A 100 V battery in series with a 100 kΩ resistor.

1-30. *Given:*

$V_S = 30$ V
$V_L = 15$ V
$R_{TH} < 2$ kΩ

Solution: Assume a value for one of the resistors. Since the Thevenin resistance is limited to 2 kΩ, pick a value less than 2 kΩ. Assume $R_2 = 1$ kΩ.

$V_L = V_S[R_2/(R_1 + R_2)]$ (Voltage divider formula)
$R_1 = [(V_S)(R_2)/V_L] - R_2$
$R_1 = [(30\text{ V})(1\text{ k}\Omega)/(15\text{ V})] - 1\text{ k}\Omega$
$R_1 = 1$ kΩ

$R_{TH} = (R_1R_2/R_1 + R_2)$
$R_{TH} = [(1\text{ k}\Omega)(1\text{ k}\Omega)]/(1\text{ k}\Omega + 1\text{ k}\Omega)$
$R_{TH} = 500\ \Omega$

Answer: The value for R_1 and R_2 is 1 kΩ. Another possible solution is $R_1 = R_2 = 4$ kΩ. *Note:* The criteria will be satisfied for any resistance value up to 4 kΩ and when both resistors are the same value.

1-31. *Given:*

$V_S = 30$ V
$V_L = 10$ V
$R_L > 1$ MΩ
$R_S < 0.01R_L$ (since the voltage source must be stiff) (Eq. 1-1)

Solution:

$R_S < 0.01R_L$
$R_S < 0.01(1\text{ M}\Omega)$
$R_S < 10$ kΩ
Since the Thevenin equivalent resistance would be the series resistance, $R_{TH} < 10$ kΩ.

Assume a value for one of the resistors. Since the Thevenin resistance is limited to 1 kΩ, pick a value less than 10 kΩ. Assume $R_2 = 5$ kΩ.

$V_L = V_S[R_2/(R_1 + R_2)]$ (Voltage divider formula)
$R_1 = [(V_S)(R_2)/V_L] - R_2$
$R_1 = [(30\text{ V})(5\text{ k}\Omega)/(10\text{ V})] - 5\text{ k}\Omega$
$R_1 = 10$ kΩ

$R_{TH} = R_1R_2/(R_1 + R_2)$
$R_{TH} = [(10\text{ k}\Omega)(5\text{ k}\Omega)]/(10\text{ k}\Omega + 5\text{ k}\Omega)$
$R_{TH} = 3.33$ kΩ

Since R_{TH} is one-third of 10 kΩ, we can use R_1 and R_2 values that are three times larger.

Answer:

$R_1 = 30$ kΩ
$B_2 = 15$ kΩ

Note: The criteria will be satisfied as long as R_1 is twice R_2 and R_2 is not greater than 15 kΩ.

1-32. *Answer:* First, measure the voltage across the terminals. This is the Thevenin voltage. Next, connect the ammeter to the battery terminals—measure the current. Next, use the values above to find the total resistance. Finally, subtract the internal resistance of the ammeter from this result. This is the Thevenin resistance.

1-33. *Answer:* First, measure the voltage across the terminals. This is the Thevenin voltage. Next, connect a resistor across the terminals. Next, measure the voltage across the resistor. Then, calculate the current through the load resistor. Then, subtract the load voltage from the Thevenin voltage. Then, divide the difference voltage by the current. The result is the Thevenin resistance.

1-34. *Solution:* Thevenize the circuit. There should be a Thevenin voltage of 0.148 V and a resistance of 6 kΩ.

$I_L = V_{TH}/(R_{TH} + R_L)$

$I_L = 0.148\text{ V}/(6\text{ k}\Omega + 0)$
$I_L = 24.7\ \mu$A

$I_L = 0.148\text{ V}/(6\text{ k}\Omega + 1\text{ k}\Omega)$
$I_L = 21.1\ \mu$A

$I_L = 0.148\text{ V}/(6\text{ k}\Omega + 2\text{ k}\Omega)$
$I_L = 18.5\ \mu$A

$I_L = 0.148\text{ V}/(6\text{ k}\Omega + 3\text{ k}\Omega)$
$I_L = 16.4\ \mu$A

$I_L = 0.148\ \text{V}/(6\ \text{k}\Omega + 4\ \text{k}\Omega)$
$I_L = 14.8\ \mu\text{A}$

$I_L = 0.148\ \text{V}/(6\ \text{k}\Omega + 5\ \text{k}\Omega)$
$I_L = 13.5\ \mu\text{A}$

$I_L = 0.148\ \text{V}/(6\ \text{k}\Omega + 6\ \text{k}\Omega)$
$I_L = 12.3\ \mu\text{A}$

Answer: 0, $I_L = 24.7\ \mu\text{A}$; 1 kΩ, $I_L = 21.1\ \mu\text{A}$; 2 kΩ, $I_L = 18.5\ \mu\text{A}$; 3 kΩ, $I_L = 16.4\ \mu\text{A}$; 4 kΩ, $I_L = 14.8\ \mu\text{A}$; 5 kΩ, $I_L = 13.5\ \mu\text{A}$; 6 kΩ, $I_L = 12.3\ \mu\text{A}$.

1-35. *Trouble:*

1: R_1 shorted
2: R_1 open or R_2 shorted
3: R_3 open
4: R_3 shorted
5: R_2 open or open at point C
6: R_4 open or open at point D
7: Open at point E
8: R_4 shorted

Chapter Two Semiconductors

SELF-TEST

1. d	**15. a**	**29. d**	**42. b**
2. a	**16. b**	**30. c**	**43. b**
3. b	**17. d**	**31. a**	**44. c**
4. b	**18. b**	**32. a**	**45. a**
5. d	**19. a**	**33. b**	**46. c**
6. c	**20. a**	**34. a**	**47. d**
7. b	**21. d**	**35. b**	**48. a**
8. b	**22. a**	**36. c**	**49. a**
9. c	**23. a**	**37. c**	**50. d**
10. a	**24. a**	**38. a**	**51. c**
11. c	**25. d**	**39. b**	**52. b**
12. c	**26. b**	**40. a**	**53. d**
13. b	**27. b**	**41. b**	**54. b**
14. b	**28. b**		

JOB INTERVIEW QUESTIONS

9. Holes do not flow in a conductor. Conductors allow current flow by virtue of their single outer-shell electron, which is loosely held. When holes reach the end of a semiconductor, they are filled by the conductor's outer-shell electrons entering at that point.

11. Because the recombination at the junction allows holes and free electrons to flow continuously through the diode.

PROBLEMS

2-1. –2

2-2. –3

2-3. **a.** Semiconductor
b. Conductor
c. Semiconductor
d. Conductor

2-4. 500,000 free electrons

2-5. **a.** 5 mA
b. 5 mA
c. 5 mA

2-6. **a.** *p*-type
b. *n*-type
c. *p*-type
d. *n*-type
e. *p*-type

2-7. *Given:*

Barrier potential at 25°C is 0.7 V
$T_{\text{min}} = 25°\text{C}$
$T_{\text{min}} = 75°\text{C}$

Solution:

$\Delta V = (-2\ \text{mV/°C})\Delta T$ (Eq. 2-4)
$\Delta V = (-2\ \text{mV/°C})(0°\text{C} - 25°\text{C})$
$\Delta V = 50\ \text{mV}$
$V_{\text{new}} = V_{\text{old}} + \Delta V$
$V_{\text{new}} = 0.7\ \text{V} + 0.05\ \text{V}$
$V_{\text{new}} = 0.75\ \text{V}$

$\Delta V = (-2\ \text{mV/°C})\Delta \text{T}$ (Eq. 2-4)
$\Delta V = (-2\ \text{mV/°C})(75°\text{C} - 25°\text{C})$
$\Delta V = -100\ \text{mV}$

$V_{\text{new}} = V_{\text{old}} + \Delta V$
$V_{\text{new}} = 0.7\ \text{V} - 0.1\ \text{V}$
$V_{\text{new}} = 0.6\ \text{V}$

Answer: The barrier potential is 0.75 V at 0°C and 0.6 V at 75°C.

2-8. *Given:*

$I_S = 10\ \text{nA at } 25°\text{C}$
$T_{\text{min}} = 0°\text{C} - 75°\text{C}$
$T_{\text{max}} = 75°\text{C}$

Solution:

$I_{S(\text{new})} = 2^{(\Delta T/10)} I_{S(\text{old})}$ (Eq. 2-5)
$I_{S(\text{new})} = 2^{[(0°\text{C} - 25°\text{C})/10]} 10\ \text{nA}$
$I_{S(\text{new})} = 1.77\ \text{nA}$

$I_{S(\text{new})} = 2^{(\Delta T/10)} I_{S(\text{old})}$ (Eq. 2-5)
$I_{S(\text{new})} = 2^{[(75°\text{C} - 25°\text{C})/10)]}\ 10\ \text{nA}$
$I_{S(\text{new})} = 320\ \text{nA}$

Answer: The saturation current is 1.77 nA at 0°C and 320 nA at 75°C.

2-9. *Given:*

$I_{SL} = 10\ \text{nA}$ with a reverse voltage of 10 V
New reverse voltage = 100 V

Solution:

$R_{SL} = V_R/I_{SL}$
$R_{SL} = 10\ \text{V}/10\ \text{nA}$
$R_{SL} = 1000\ \text{M}\Omega$

$I_{SL} = V_R/R_{SL}$
$I_{SL} = 100\ \text{V}/1000\ \text{M}\Omega$
$I_{SL} = 100\ \text{nA}$

Answer: 100 nA.

2-10. *Answer:* Saturation current is 0.53 µA, and surface-leakage current is 4.47 µA at 25°C.

2-11. Reduce the saturation current, and minimize the RC time constants.

Chapter 3 Diode Theory

SELF-TEST

1. b	**7. c**	**12. b**	**17. b**
2. b	**8. c**	**13. a**	**18. b**
3. c	**9. a**	**14. d**	**19. a**
4. d	**10. a**	**15. a**	**20. a**
5. a	**11. b**	**16. c**	**21. c**
6. b			

Answer:

$I_L = 19.3$ mA
$V_L = 19.3$ V
$P_L = 372$ mW
$P_D = 13.4$ mW
$P_T = 386$ mW

3-15. *Given:*

$V_S = 20$ V
$V_D = 0.7$ V
$R_L = 2$ kΩ

Solution:

$I_L = V_L/R_L$ (Ohm's law)
$I_L = 19.3$ V/2 kΩ
$I_L = 9.65$ mA

Answer: 9.65 mA

3-16. *Given:*

$V_S = 12$ V
$V_D = 0.7$ V
$R_L = 470$ Ω

Solution:

$V_S = V_D + V_L$ (Kirchhoff's law)
12 V = 0.7 V + V_L
$V_L = 11.3$ V

$I_L = V_L/R_L$ (Ohm's law)
$I_L = 11.3$ V/470 Ω
$I_L = 24$ mA

$P_L = (V_L)(I_L)$
$P_L = (11.3$ V)(24 mA)
$P_L = 271.2$ mW

$P_D = (V_D)(I_D)$
$P_D = (0.7$ V)(24 mA)
$P_D = 29.2$ mW

$P_T = P_D + P_L$
$P_T = 29.2$ mW + 271.2 mW
$P_T = 300.4$ mW

Answer:

$V_L = 11.3$ V
$I_L = 24$ mA
$P_L = 271.2$ mW
$P_D = 29.2$ mW
$P_T = 300.4$ mW

3-17. *Given:*

$V_S = 12$ V
$V_D = 0.7$ V
$R_L = 940$ Ω

Solution:

$V_S = V_D + V_L$ (Kirchhoff's law)
12 V = 0.7 V + V_L
$V_L = 11.3$ V

$I_L = V_L/R_L$ (Ohm's law)
$I_L = 11.3$ V/940 Ω
$I_L = 12$ mA

Answer: 12 mA

3-18. *Given:*

$V_S = 12$ V
$R_L = 470$ Ω

Solution: The diode would be reversed-based and acting as an open. Thus the current would be zero, and the voltage would be source voltage.

Answer:

$V_D = 12$ V
$I_D = 0$ mA

3-19. *Open*

3-20. The diode voltage will be 5 V, and it should burn open the diode.

3-21. The diode is shorted, or the resistor is open.

3-22. The voltage of 3 V at the junction of R_1 and R_2 is normal if it is a voltage divider with nothing in parallel with R_2. So, the problem is in the parallel branch. A reading of 0 V at the diode resistor junction indicates either a shorted resistor (not likely) or an open diode. A solder bridge could cause the resistor to appear to be shorted.

3-23. A reverse diode test reading of 1.8 V indicates a leaky diode.

3-24. 1N4004

3-25. Cathode band. The arrow points toward the band.

3-26. The temperature limit is 175°C, and the temperature of boiling water is 100°C. Therefore, the temperature of the boiling water is less than the maximum temperature and the diode will not be destroyed.

CRITICAL THINKING

3-27. *Given:*

1N914: forward 10 mA at 1 V; reverse 25 nA at 20 V
1N4001: forward 1 A at 1.1 V; reverse 10 µA at 50 V
1N1185: forward 10 A at 0.95 V; reverse 4.6 mA at 100 V

Solution:

1N914 forward:
$R = V/I$ (Ohm's law)
$R = 1$ V/10 mA
$R = 100$ Ω

1N914 reverse:
$R = V/I$ (Ohm's law)
$R = 20$ V/25 nA
$R = 800$ MΩ

1N4001 forward:
$R = V/I$ (Ohm's law)
$R = 1.1$ V/1 A
$R = 1.1$ Ω

1N4001 reverse:
$R = V/I$ (Ohm's law)
$R = 50$ V/10 µA
$R = 5$ MΩ

1N1185 forward:
$R = V/I$ (Ohm's law)
$R = 0.95$ V/10 A
$R = 0.095$ Ω

1N1185 reverse:
$R = V/I$ (Ohm's law)
$R = 100$ V/4.6 mA
$R = 21.7$ kΩ

Answer:

1N914:
forward $R = 100\ \Omega$
reverse $R = 800\ \text{M}\Omega$

1N4001:
forward $R = 1.1\ \Omega$
reverse $R = 5\ \text{M}\Omega$

1N1185:
forward $R = 0.095\ \Omega$
reverse $R = 21.7\ \text{k}\Omega$

3-28. *Given:*

$V_S = 5$ V
$V_D = 0.7$ V
$I_D = 20$ mA

Solution:

$V_R = V_S - V_D$ (Kirchhoff's law)
$V_R = 5\text{ V} - 0.7\text{ V}$
$V_R = 4.3$ V

$R = V/I$ (Ohm's law)
$R = 4.3\text{ V}/20\text{ mA}$
$R = 215\ \Omega$

Answer: $R = 215\ \Omega$

3-29. *Given:*

$V_D = 0.7$ V
$I_D = 10$ mA
$R_1 = 30\ \text{k}\Omega$
$R_3 = 5\ \text{k}\Omega$

Solution: Find the voltage required on the parallel branch to achieve a diode current of 0.25 mA.

$V_R = IR_3$ (Ohm's law)
$V_R = (0.25\text{ mA})(5\ \text{k}\Omega)$
$V_R = 1.25$ V
$V = V_R + V_D$ (Kirchhoff's law)
$V = 1.25\text{ V} + 0.7\text{ V}$
$V = 1.95\ V$

This is the voltage at the junction of R_1 and R_2. Next find the voltage drop across R_1.

$V_{R1} = V_S - V$ (Kirchhoff's law)
$V_{R1} = 12\text{ V} - 1.95\text{ V}$
$V_{R1} = 10.05$ V

$I = V/R$ (Ohm's law)
$I = 10.05\text{ V}/30\ \text{k}\Omega$
$I = 335\ \mu\text{A}$

Now that the current through R_1 is known, this is the total current for the parallel branches. The nest step is to find the current through R_2.

$I_2 = I_1 - I_D$ (Kirchhoff's law)
$I_2 = 335\ \mu\text{A} - 0.25\text{ mA}$
$I_2 = 85\ \mu\text{A}$

The next step is to use the voltage and current to calculate the resistance.

$R_2 = V/I_2$ (Ohm's law)
$R_2 = 1.95\text{ V}/85\ \mu\text{A}$
$R_2 = 23\ \text{k}\Omega$

Answer: $R_2 = 23\ \text{k}\Omega$

3-30. *Given:*

500 mA at 1 V
0 mA at 0.7 V

Solution:

$r_B = (V_2 - V_1)(I_2 - I_1)$ (Eq. 3-7)
$r_B = (1\text{ V} - 0.7\text{ V})/(500\text{ mA} - 0\text{ mA})$
$r_B = 600\text{ m}\Omega$

Answer: $r_B = 600\text{ m}\Omega$

3-31.

1. $I_R = I_{SL} + I_S$
2. $5\ \mu\text{A} = I_{SL} + I_{S(\text{old})}$
3. $I_{SL} = 5\ \mu\text{A} - I_{S(\text{old})}$
4. $100\ \mu\text{A} = I_{SL} + I_{S(\text{new})}$
5. $I_{S(\text{new})} = 2^{(\Delta T/10)}\ I_{S(\text{old})}$ (Eq. 2-6)
   Substitute formulas 2 and 5 into formula 4.
6. $100\ \mu\text{A} = 5\ \mu\text{A} - I_{S(\text{old})} + 2^{(\Delta T/10)} I_{S(\text{old})}$
   Put in the temperature values.
7. $100\ \mu\text{A} = 5\ \mu\text{A} - I_{S(\text{old})} + 2^{[(100^\circ\text{C} - 25^\circ\text{C})/10]} I_{S(\text{old})}$
   Move the 5 μA to the left side, and simplify the exponent of 2.
8. $95\ \mu\text{A} = -I_{S(\text{old})} + 2^{7.5}\ I_{S(\text{old})}$
   Combine like terms.
9. $95\ \mu\text{A} = (2^{7.5} - 1) I_{S(\text{old})}$
10. $95\ \mu\text{A} = (180.02)\ I_{S(\text{old})}$
    Solve for the variable.
11. $I_{S(\text{old})} = 95\ \mu\text{A}/(180.02)$
12. $I_{S(\text{old})} = 0.53\ \mu\text{A}$
    Using formula 3:
13. $I_{SL} = 5\ \mu\text{A} - I_{S(\text{old})}$
14. $I_{SL} = 5\ \mu\text{A} - 0.53\ \mu\text{A}$
15. $I_{SL} = 4.47\ \mu\text{A}$

Answer: The surface-leakage current is 4.47 μA at 25°C.

3-32. *Given:*

$R_1 = 30\ \text{k}\Omega$
$R_2 = 10\ \text{k}\Omega$
$R_3 = 5\ \text{k}\Omega$

This condition will not occur if the diode is normal. It can be either opened or shorted. If it is shorted, the resistance would be 0 Ω. If it is open, it would be the resistance of the resistors.

Solution: The circuit would have R_1 and R_2 in parallel, and the parallel resistance in series with R_3.

$R = [(R_1)(R_2)]/(R_1 + R_2)$ (Parallel resistance formula)
$R = [(30\ \text{k}\Omega)(10\ \text{k}\Omega)]/(30\ \text{k}\Omega + 10\ \text{k}\Omega)$
$R = 7.5\ \text{k}\Omega$
$R_T = 5\ \text{k}\Omega + 7.5\ \text{k}\Omega$
$R_T = 12.5\ \text{k}\Omega$

Answer: The resistance would be 12.5 kΩ if the diode is open and 0 Ω if the diode is shorted.

3-33. During normal operation, the 15-V power supply is supplying power to the load. The left diode is forward-biased and allows the 15-V power supply to supply current to the load. The right diode is reversed-based because 15 V is applied to the cathode and only 12 V is applied to the anode. This blocks the 12-V battery. Once the 15-V power supply is lost, the right diode is no longer reversed-biased, and the 12-V battery can supply current to the load. The left diode will become reverse-biased, preventing any current from going into the 15-V power supply.

3-34. It causes all of them to increase.

3-35. The source voltage does not change, but all other variables decrease.

3-36. I_1, I_2, and P_1. Because the resistance of R_2 increased, the total resistance of the voltage divider increases. This causes the current in the voltage divider to decrease. This explains the decreasing of the current. Since the voltage across R_1 decreased and I_1 decreased, P_1 decreases.

3-37. V_A, V_B, V_C, I_1, I_2, P_1, P_2. Since R is so large, it has no effect on the voltage divider; therefore, the variables associated with the voltage divider do not change.

3-38. V_C, I_3, P_3. The voltage divider is unaffected. The increase in diode voltage drop will cause the voltage at point C to decrease, thus decreasing the current and power.

Chapter 4 Diode Circuits

SELF-TEST

1. b	**8. c**	**14. a**	**20. c**
2. a	**9. c**	**15. b**	**21. a**
3. b	**10. d**	**16. a**	**22. b**
4. c	**11. b**	**17. d**	**23. a**
5. c	**12. b**	**18. c**	**24. c**
6. b	**13. c**	**19. c**	**25. c**
7. b			

JOB INTERVIEW QUESTIONS

7. The *LC* type is preferable when tighter regulation is required and (or) power cannot be wasted. Examples include transmitters, lab test equipment, and military gear when cost is not of primary concern. The *LC* filter ideally dissipates no power. In reality, the inductor losses result in some heal. The less costly *RC* filter consumes power in the resistor.

8. A full-wave rectifier is made up of two back-to-back half-wave rectifiers.

9. When you need a high dc output voltage from the power supply, but a step-up transformer is neither available nor practical in the design.

11. Because a transformer with a high turns ratio produces a few thousand volts, which means more insulation and expense.

13. There is probably a short in the circuit that caused excessive current through the resistor. You have to look at the schematic diagram and test the different components and wiring to try to locate the real trouble.

PROBLEMS

4-1. *Given:* $V_{\text{in}} = 50$ V ac

Solution:

$V_P = 1.414\ \text{V}_{\text{rms}}$
$V_P = 1.414\ (50\ \text{V ac})$
$V_P = 70.7$ V

$V_{p(\text{out})} = V_{p(\text{in})}$ (Eq. 4-1)
$V_{p(\text{out})} = 70.7$ V

Since the average and the dc values are the same:

$V_{\text{dc}} = 0.318\ \text{V}_P$ (Eq. 4-2)
$V_{\text{dc}} = 0.318\ (70.7\ \text{V})$
$V_{\text{dc}} = 22.5$ V

Answer: The peak voltage is 70.7 V, the average voltage is 22.5 V, and the dc voltage is 22.5 V.

4-2. *Given:* $V_{\text{in}} = 15$ V ac

Solution:

$V_P = 1.414\ \text{V}_{\text{rms}}$
$V_P = 1.414\ (15\ \text{V ac})$
$V_P = -21.2$ V

$V_{p(\text{out})} = V_{p(\text{in})}$ (Eq. 4-1)
$V_{p(\text{out})} = -21.2$ V

Since the average and the dc values are the same:

$V_{\text{dc}} = 0.318\ \text{V}_{\text{p}}$ (Eq. 4-2)
$V_{\text{dc}} = 0.318\ (-21.2\ \text{V})$
$V_{\text{dc}} = -6.74$ V

Answer: The peak voltage is –21.2 V, the average voltage is –6.74 V, and the dc voltage is –6.74 V.

4-3. *Given:* $V_{\text{in}} = 50$ V ac

Solution:

$V_P = 1.414\ \text{V}_{\text{rms}}$
$V_P = 1.414\ (50\ \text{V ac})$
$V_P = 70.7$ V

$V_{p(\text{out})} = V_{p(\text{in})} - 0.7$ V (Eq. 4-4)
$V_{p(\text{out})} = 70.0$ V

Since the average and the dc values are the same:

$V_{\text{dc}} = 0.318$ V (Eq. 4-2)
$V_{\text{dc}} = 0.318\ (70.0\ \text{V})$
$V_{\text{dc}} = 22.3$ V

Answer: The peak voltage is 70.0 V, the average voltage is 22.3 V, and the dc voltage is 22.3 V.

4-4. *Given:* $V_{\text{in}} = 15$ V ac

Solution:

$V_P = 1.414\ \text{V}_{\text{rms}}$
$V_P = 1.414\ (15\ \text{V ac})$
$V_P = -21.2$ V

$V_{p(\text{out})} = V_{p(\text{in})} - 0.7$ V (Eq. 4-4)
$V_{p(\text{out})} = -20.5$ V

Since the average and the DC values are the same:

$V_{\text{dc}} = 0.318$ V (Eq. 4-2)
$V_{\text{dc}} = 0.318\ (-20.5\ \text{V})$
$V_{\text{dc}} = -6.52$ V

Answer: The peak voltage is –20.5 V, the average voltage is –6.52 V, and the dc voltage is –6.52 V.

Output waveform for Probs. 4-1 and 4-3. Waveform is negative for Probs. 4-2 and 4-4.

4-5. *Given:*

Turns ratio = $N_1/N_2 = 6{:}1 = 6$
$V_1 = 120\ \text{V}_{\text{rms}}$

Solution:

$V_2 = V_1/(N_1/N_2)$ (Eq. 4-5)
$V_2 = 120\ \text{V}_{\text{rms}}/6$
$V_2 = 20\ \text{V}_{\text{rms}}$

$V_P = (1.414)\ (\text{V}_{\text{rms}})$
$V_P = (1.414)\ (20\ \text{V}_{\text{rms}})$
$V_P = 28.28\ V_P$

Answer: The secondary voltage is 20 V_{rms} or 28.28 V_P.

4-6. *Given:*

Turns ratio = $N_1/N_2 = 1{:}12 = 0.083333$
$V_1 = 120$ V ac

Solution:

$V_2 = V_1/(N_1/N_2)$ (Eq. 4-5)
$V_2 = 120$ V ac/0.083333
$V_2 = 1440$ V ac

$V_P = 1.414\ \text{V}_{\text{rms}}$
$V_P = 1.414\ (1440\ \text{V ac})$
$V_P = 2036.16$ V

Answer: The secondary rms voltage is 1440 V ac, and the peak voltage is 2036.16 V.

4-7. *Given:*

Turns ratio = $N_1/N_2 = 8 : 1 = 8$
$V_1 = 120$ V ac (rms)

Solution:

$V_2 = V_1/(N_1/N_2)$ (Eq. 4-5)
$V_2 = 120$ V ac/8
$V_2 = 15$ V ac

$V_P = 1.414\ V_{rms}$
$V_P = 1.414$ (15 V ac)
$V_P = 21.21$ V

$V_{p(out)} = V_{p(in)}$ (Eq. 4-1)
$V_{p(out)} = 21.21$ V

$V_{dc} = 0.318\ V_P$ (Eq. 4-2)
$V_{dc} = 0.318$ (21.21 V)
$V_{dc} = 6.74$ V

Answer: The peak voltage is 21.21 V, and the dc voltage is 6.74 V.

4-8. *Given:*

Turns ratio = N_1/N_2 = 8:1 = 8
$V_1 = 120$ V ac (rms)

Solution:

$V_2 = V_1/(N_1/N_2)$ (Eq. 4-5)
$V_2 = 120$ V ac/8
$V_2 = 15$ V ac

$V_P = 1.414\ V_{rms}$
$V_P = 1.414$ (15 V ac)
$V_P = 21.21$ V

$V_{p(out)} = V_{p(in)} - 0.7$ V (Eq. 4-4)
$V_{p(out)} = 20.51$ V

$V_{dc} = 0.318\ V_P$ (Eq. 4-2)
$V_{dc} = 0.318$ (20.51 V)
$V_{dc} = 6.52$ V

Answer: The peak voltage is 20.51 V, and the dc voltage is 6.52 V.

4-9. *Given:*

Turns ratio = N_1/N_2 = 4:1 = 4
$V_1 = 120\ V_{rms}$

Solution:

$V_2 = V_1/(N_1/N_2)$ (Eq. 4-5)
$V_2 = 120\ V_{rms}/4$
$V_2 = 30\ V_{rms}$

Since it is a center-tapped transformer, each half of the secondary is half of the total secondary voltage.

$V_{upper} = ½\ V_2$
$V_{upper} = ½\ (30\ V_{rms})$
$V_{upper} = 15\ V_{rms}$

$V_{lower} = ½\ V_P$
$V_{lower} = ½(30\ V_{rms})$
$V_{lower} = 15\ V_{rms}$

$V_P = (1.414)\ (V_{rms})$
$V_P = (1.414)\ (15\ V_{rms})$
$V_P = 21.21\ V_P$

Answer: Each half of the secondary has an rms voltage of 15 V and a peak voltage of 21.21 V.

4-10. *Given:*

Turns ratio = N_1/N_2 = 7:1 = 7
$V_1 = 120$ V ac

Solution:

$V_2 = V_1/(N_1/N_2)$ (Eq. 4-5)
$V_2 = 120$ V ac/7
$V_2 = 17.14$ V ac

$V_P = 1.414\ V_{rms}$
$V_P = 1.414$ (17.14 V ac)
$V_P = 24.24$ V

$V_{P(in)} = 0.5\ V_P$
$V_{P(in)} = 0.5(24.24$ V)
$V_{P(in)} = 12.12$ V

$V_{p(out)} = V_{p(in)}$ (Eq. 4-1)
$V_{p(out)} = 12.12$ V

Since the average and the dc values are the same:

$V_{dc} = 0.636\ V_p$ (Eq. 4-6)
$V_{dc} = 0.636$ (12.12 V)
$V_{dc} = 7.71$ V

Answer: The peak output voltage is 12.12 V, and the dc and average values are 7.71 V.

4-11. *Given:*

Turns ratio = N_1/N_2 = 7:1 = 7
$V_1 = 120$ V ac

Solution:

$V_2 = V_1/(N_1/N_2)$ (Eq. 4-5)
$V_2 = 120$ V ac/7
$V_2 = 17.14$ V ac

$V_P = 1.414\ V_{rms}$
$V_P = 1.414$ (17.14 V ac)
$V_P = 24.24$ V

$V_{P(in)} = 0.5\ V_P$
$V_{P(in)} = 0.5(24.24$ V)
$V_{P(in)} = 12.12$ V

$V_{p(out)} = V_{p(in)} - 0.7$ V (Eq. 4-4)
$V_{p(out)} = 11.42$ V

Since the average and the dc values are the same:

$V_{dc} = 0.636\ V_P$ (Eq. 4-6)
$V_{dc} = 0.636$ (11.42 V)
$V_{dc} = 7.26$ V

Answer: The peak output voltage is 11.42 V, and the dc and average values are 7.26 V.

4-12. *Given:*

Turns ratio = N_1/N_2 = 8:1 = 8
$V_1 = 120$ V ac

Solution:

$V_2 = V_1/(N_1/N_2)$ (Eq. 4-5)
$V_2 = 120$ V ac/8
$V_2 = 15$ V ac

$V_{P(in)} = 1.414\ V_{rms}$
$V_{P(in)} = 1.414$ (15 V ac)
$V_{P(in)} = 21.21$ V

$V_{p(out)} = V_{p(in)}$ (Eq. 4-1)
$V_{p(out)} = 21.21$ V

Since the average and the dc values are the same:

$V_{dc} = 0.636\ V_p$ (Eq. 4-6)
$V_{dc} = 0.636$ (21.21 V)
$V_{dc} = 13.49$ V

Answer: The peak output voltage is 21.21 V, and the dc and average values are 13.49 V.

4-13. *Given:*

Turns ratio = N_1/N_2 = 8:1 = 8
V_1 = 120 V ac

Solution:

$V_2 = V_1/(N_1/N_2)$ (Eq. 4-5)
V_2 = 120 V ac/8
V_2 = 15 V ac

$V_{P(\text{in})}$ = 1.414 V_{rms}
$V_{P(\text{in})}$ = 1.414 (15 V ac)
$V_{P(\text{in})}$ = 21.21 V

$V_{p(\text{out})} = V_{p(\text{in})}$ – 1.4 V (Eq. 4-8)
$V_{p(\text{out})}$ = 19.81 V

Since the average and the dc values are the same:

V_{dc} = 0.636 V_p (Eq. 4-6)
V_{dc} = 0.636 (19.81 V)
V_{dc} = 12.60 V

Answer: The peak output voltage is 19.81 V, and the dc and average values are 12.60 V.

Output waveform for Probs. 4-10 to 4-13.

4-14. *Given:*

Turns ratio = N_1/N_2 = 8:1 = 8
$V_{1(\text{max})}$ = 125 V ac
$V_{1(\text{min})}$ = 102 V ac

Solution:

$V_{2(\text{max})} = V_{1(\text{max})}/(N_1/N_2)$ (Eq. 4-5)
$V_{2(\text{max})}$ = 125 V ac/8
$V_{2(\text{max})}$ = 15.63 V ac

$V_{2(\text{min})} = V_{1(\text{min})}/(N_1/N_2)$ (Eq. 4-5)
$V_{2(\text{min})}$ = 105 V ac/8
$V_{2(\text{min})}$ = 13.13 V ac

$V_{P(\text{in})\text{max}}$ = 1.414 $V_{2(\text{max})}$
$V_{P(\text{in})\text{max}}$ = 1.414 (15.63 V ac)
$V_{P(\text{in})\text{max}}$ = 22.10 V

$V_{P(\text{in})\text{min}}$ = 1.414 $V_{2(\text{min})}$
$V_{P(\text{in})\text{min}}$ = 1.414 (13.13 V ac)
$V_{P(\text{in})\text{min}}$ = 18.57 V

$V_{p(\text{out})\text{max}} = V_{\text{p(in)max}}$ (Eq. 4-1)
$V_{p(\text{out})\text{max}}$ = 22.10 V

$V_{p(\text{out})\text{min}} = V_{p(\text{in})\text{min}}$ (Eq. 4-1)
$V_{p(\text{out})\text{min}}$ = 18.57 V

$V_{\text{dc(max)}}$ = 0.636 $V_{p(\text{out})\text{max}}$ (Eq. 4-6)
V_{dc} = 0.636 (22.10 V)
V_{dc} = 14.06 V

$V_{\text{dc(min)}}$ = 0.636 $V_{p(\text{out})\text{min}}$ (Eq. 4-6)
V_{dc} = 0.636 (18.57 V)
V_{dc} = 11.81 V

Answer: The maximum dc output voltage is 14.06 V, and the minimum is 11.81 V.

4-15. *Given:*

V_{in} = 20 V
X_L = 1 kΩ
X_C = 25 Ω

Solution:

$V_{\text{out}} = (X_C/X_L)V_{\text{in}}$ (Eq. 4-9)
V_{out} = (25 Ω/1 kΩ)(20 V)
V_{out} = 500 mV

Answer: The ripple voltage would be 500 mV.

4-16. *Given:*

V_{in} = 14 V
X_L = 2 kΩ
X_C = 50 Ω

Solution:

$V_{\text{out}} = (X_C/X_L)V_{\text{in}}$ (Eq. 4-9)
V_{out} = (50 Ω/2 kΩ)(14 V)
V_{out} = 350 mV

Answer: The ripple voltage would be 350 mV.

4-17. *Given:*

Turns ratio = N_1/N_2 = 8:1 = 8
V_1 = 120 V ac
R_L = 10 kΩ
C = 47 µF
f_{in} = 60 Hz

Solution:

$V_2 = V_1/(N_1/N_2)$ (Eq. 4-5)
V_2 = 120 V ac/8
V_2 = 15 V ac

V_P = 1.414 V_2
V_P = 1.414 (15 V ac)
V_P = 21.2 V (This is the dc output voltage due to the capacitor input filter.)

$I = V/R$ (Ohm's law)
I = 21.2 V/10 kΩ
I = 2.12 mA

$f_{\text{out}} = f_{\text{in}}$ (Eq. 4-3)
f_{out} = 60 Hz

$V_R = I/(fC)$ (Eq. 4-10)
V_R = (2.12 mA)/[(60 Hz)(47 µF)]
V_R = 752 mV

Answer: The dc output voltage is 21.2 V with a 752 mV pp ripple.

Output waveform for Prob. 4-17.

4-18. *Given:*

Turns ratio = N_1/N_2 = 7:1 = 7
V_1 = 120 V ac
R_L = 2.2 kΩ
C = 68 µF
f_{in} = 60 Hz

Solution:

$V_2 = V_1/(N_1/N_2)$ (Eq. 4-5)
V_2 = 120 V ac/7
V_2 = 17.14 V ac

V_P = 1.414 V_{rms}
V_P = 1.414 (17.14 V ac)
V_P = 24.24 V

$V_{P(\text{in})}$ = 0.5 V_P
$V_{P(\text{in})}$ = 0.5(24.24 V)
$V_{P(\text{in})}$ = 12.12 V

$V_{p(\text{out})} = V_{p(\text{in})}$ (Eq. 4-1)
$V_{p(\text{out})}$ = 12.12 V (This is the dc output voltage due to the capacitor input filter.)

$I = V/R$ (Ohm's law)
$I = 12.12\ V/2.2\ k\Omega$
$I = 5.51\ mA$

$f_{out} = 2f_{in}$ (Eq. 4-7)
$f_{out} = 2(60\ Hz)$
$f_{out} = 120\ Hz$

$V_R = I/(fC)$ (Eq. 4-10)
$V_R = (5.51\ mA)/[(120\ Hz)(68\ \mu F)]$
$V_R = 675\ mV$

Answer: The dc output voltage is 12.12 V, with a 675 mV pp ripple.

4-19. *Answer:*

$V_R = I/(fC)$ (Eq. 4-10)
If the capacitance is cut in half, the denominator is cut in half and the ripple voltage will double.

4-20. *Answer:*

$V_R = I/(fC)$ (Eq. 4-10)
If the resistance is reduced to 500 Ω, the current increases by a factor of 20; thus the numerator is increased by a factor of 20 and the ripple voltage goes up by a factor of 20.

4-21. *Given:*

Turns ratio = $N_1/N_2 = 9{:}1 = 9$
$V_1 = 120\ V\ ac$
$R_L = 1\ k\Omega$
$C = 470\ \mu F$
$f_{in} = 60\ Hz$

Solution:

$V_2 = V_1/(N_1/N_2)$ (Eq. 4-5)
$V_2 = 120\ V\ ac/9$
$V_2 = 13.33\ V\ ac$

$V_P = 1.414\ V_{rms}$
$V_P = 1.414\ (13.33\ V\ ac)$
$V_P = 18.85\ V$

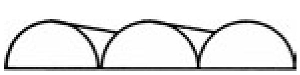
$V_{p(out)} = V_p$ (Eq. 4-1)
$V_{p(out)} = 18.85\ V$ (This is the dc output voltage due to the capacitor input filter.)

$I = V/R$ (Ohm's law)
$I = 18.85\ V/1\ k\Omega$
$I = 18.85\ mA$

$f_{out} = 2f_{in}$ (Eq. 4-7)
$f_{out} = 2(60\ Hz)$
$f_{out} = 120\ Hz$

$V_R = I/(fC)$ (Eq. 4-10)
$V_R = (18.85\ mA)/[(120\ Hz)(470\ \mu F)]$
$V_R = 334\ mV$

Answer: The dc output voltage is 18.85 V, with a 334 mV pp ripple.



Output waveform for Probs. 4-18 and 4-21.

4-22. *Given:*

Turns ratio = $N_1/N_2 = 9{:}1 = 9$
$V_1 = 105\ V\ ac$
$R_L = 1\ k\Omega$
$C = 470\ \mu F$
$f_{in} = 60\ Hz$

Solution:

$V_2 = V_1/(N_1/N_2)$ (Eq. 4-5)
$V_2 = 105\ V\ ac/9$
$V_2 = 11.67\ V\ ac$

$V_P = 1.414\ V_{rms}$
$V_P = 1.414\ (11.67\ V\ ac)$
$V_P = 16.50\ V$

$V_{p(out)} = V_P$ (Eq. 4-1)
$V_{p(out)} = 16.50\ V$ (This is the dc output voltage due to the capacitor input filter.)

4-23. *Given:* $V_P = 18.85\ V_P$ from Prob. 4-21

Solution:

PIV = V_P (Eq. 4-13)
PIV = 18.85 V

Answer: The peak inverse voltage is 18.85 V.

4-24. *Given:*

Turns ratio = $N_1/N_2 = 3{:}1 = 3$
$V_1 = 120\ V_{rms}$

Solution:

$V_2 = V_1/(N_1/N_2)$ (Eq. 4-5)
$V_2 = 120\ V_{rms}/3$
$V_2 = 40\ V_{rms}$

$V_P = (1.414)\ (V_{rms})$
$V_P = (1.414)\ (40\ V_{rms})$
$V_P = 56.56\ V_P$

PIV = V_P (Eq. 4-13)
PIV = 56.56 V

Answer: The peak inverse voltage is 56.56 V.

4-25. *Solution:*

From the information on p. 114.
a. Secondary output is 12.6 V ac.
$V_P = 1.414\ V_{rms}$
$V_P = 1.414\ (12.6\ V\ ac)$
$V_P = 17.8\ V$
b. $V_{dc} = 17.8\ V$
c. $I = V/R$ (Ohm's law)
$I_{dc} = 17.8\ V\ ac/1\ k\Omega$
$I_{dc} = 17.8\ mA$
Rated current is 1.5 A.

Answer: The peak output voltage is 17.8 V, and the dc output voltage is 17.8 V. It is not operating at rated current, and thus the secondary voltage will be higher.

4-26. *Given:*

Assume $P_{in} = P_{out}$
$V_{dc} = 17.8\ V$ from Prob. 4-25
$I_{dc} = 17.8\ mA$ from Prob. 4-25

Solution:

$P_{out} = I_{dc}\ V_{dc}$
$P_{out} = (17.8\ mA)(17.8\ V)$
$P_{out} = 317\ mW$
$P_{in} = 317\ mW$
$P_{in} = V_1 I_{pri}$
$I_{pri} = P_{in}/V_1$
$I_{pri} = 317\ mW/120\ V$
$I_{pri} = 2.64\ mA$

Answer: The primary current would be 2.64 mA.

4-27. *Given:*

$V_{DC} = 21.2\ V$ from Prob. 4-17
$V_{DC} = 12.12\ V$ from Prob. 4-18

Solution:

Fig. 4-40(a)

$I_{diode} = V/R$
$I_{diode} = (2.12\ V)/(10\ k\Omega)$
$I_{diode} = 2.12\ mA$

Fig. 4-40(b)
$I = V/R$
$I = (12.12\ V)/(2.2\ k\Omega)$
$I = 5.5\ mA$

$I_{diode} = 0.5\ I$
$I_{diode} = (0.5)/(5.5\ mA)$
$I_{diode} = 2.75\ mA$

Answer: The average diode current in Fig. 4-40(a) is 212 μA and the current in Fig. 4-40(b) is 2.75 mA.

4-28 *Given:* I_{dc} = 18.85 mA from Prob. 4-21

Solution:

$I_{diode} = (0.5)I_{dc}$
$I_{diode} = (0.5)(18.85\ mA)$
$I_{diode} = 9.43\ mA$

4-29 *Given:* $V_{p(out)}$ = 18.85 V from Prob. 4-21

Solution: Without the filter capacitor to maintain the voltage at peak, the dc voltage is calculated the same way it would be done if the filter was not there.

$V_{dc} = 0.636\ V_P$
$V_{dc} = 0.636(18.85\ V)$
$V_{dc} = 11.99\ V$

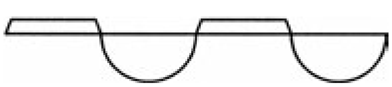
Answer: The dc voltage is 11.99 V.

4-30. *Answer:* With one diode open, one path for current flow is unavailable. The output will look similar to a half-wave rectifier with a capacitor input filter. The dc voltage should not change from the original 18.85 V, but the ripple will increase to approximately double because the frequency drops from 120 to 60 Hz.

4-31. *Answer:* Since an electrolytic capacitor is polarity-sensitive, if it is put in backward, it will be destroyed and the power supply will act as if it did not have a filter.

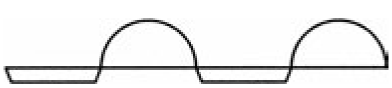
4-32. *Answer:* V_P will remain the same, DC output equals V_P, V_{ripple} = 0 V.

4-33. *Answer:* Since this is a positive clipper, the maximum positive will be the diode's forward voltage, and all the negative will be passed through. Maximum positive is 0.7 V, and maximum negative is –50 V.



Output waveform for Prob. 4-33.

4-34. *Answer:* Since this is a negative clipper, the maximum negative will be the diode's forward voltage, and all the positive will be passed through. The maximum positive is 24 V, and the maximum negative is –0.7 V.



Output waveform for Prob. 4-34.

4-35. *Answer:* The limit in either direction is two diode voltage drops. Maximum positive is 1.4 V, and maximum negative is –1.4 V.

4-36. *Given:*

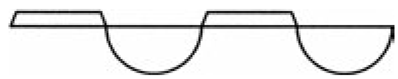
DC voltage 15 V
$R_1 = 1\ k\Omega$
$R_2 = 6.8\ k\Omega$

Solution:

Voltage at the cathode is found by using the voltage divider formula.
$V_{bias} = [R_1/(R_1 + R_2)]V_{dc}$ (Eq. 4-18)
$V_{bias} = [1\ k\Omega/(1\ k\Omega + 6.8\ k\Omega)]15\ V$
$V_{bias} = 1.92\ V$

The clipping voltage is the voltage at the cathode and the diode voltage drop.
$V_{clip} = 1.92\ V + 0.7\ V$
$V_{clip} = 2.62\ V$

Answer: Since it is a positive clipper, the positive voltage is limited to 2.62 V and the negative to –20 V.



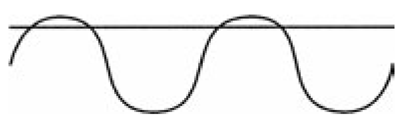
Output waveform for Prob. 4-36.

4-37. *Answer:* The output will always be limited to 2.62 V.

4-38. *Answer:* Since this is a positive clamper, the maximum negative voltage will be –0.7 V and the maximum positive will be 29.3 V.

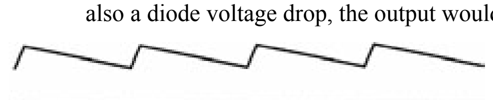
Output waveform for Prob. 4-38.

4-39. *Answer:* Since this is a negative clamper, the maximum positive voltage will be 0.7 V and the maximum negative will be –59.3 V.



Output waveform for Prob. 4-39.

4.40. *Answer:* The output will be $2V_P$ or V_{pp}, which is 40 V. If the second approximation is used, the maximum for the clamp will be 39.3 V instead of 40 V, and since there is also a diode voltage drop, the output would be 38.6 V.



Output waveform for Prob. 4-40.

4-41. *Given:*

Turns ratio = N_1/N_2 = 1:10 = 0.1
V_1 = 120 V ac

Solution:

$V_2 = V_1/(N_1/N_2)$ (Eq. 4-5)
V_2 = 120 V ac/0.1
V_2 = 1200 V ac

$V_P = 1.414\ V_{rms}$
V_P = 1.414 (1200 V ac)
V_P = 1696.8 V

Since it is a doubler, the output is $2V_P$.

$V_{out} = 2V_P$
V_{out} = 2 (1696.8 V)
V_{out} = 3393.6 V

Answer: The output voltage will be 3393.6 V.

4-42. *Given:*

Turns ratio = N_1/N_2 = 1:5 = 0.2
V_1 = 120 V ac

Solution:

$V_2 = V_1/(N_1/N_2)$ (Eq. 4-5)
$V_2 = 120$ V ac/0.2
$V_2 = 600$ V ac

$V_P = 1.414\ V_{rms}$
$V_P = 1.414$ (600 V ac)
$V_P = 848.4$ V

Since it is a tripler, the output is $3V_P$.
$V_{out} = 3V_P$
$V_{out} = 3$ (848.4 V)
$V_{out} = 2545.2$ V

Answer: The output voltage will be 2545.2 V.

4-43. *Given:*

Turns ratio = N_1/N_2 = 1:7 = 0.143
$V_1 = 120$ V ac

Solution:

$V_2 = V_1/(N_1/N_2)$ (Eq. 4-5)
$V_2 = 120$ V ac/0.143
$V_2 = 839.2$ V ac

$V_P = 1.414\ V_{rms}$
$V_P = 1.414$ (839.2 V ac)
$V_P = 1186.6$ V

Since it is a quadrupler, the output is $4V_P$.
$V_{out} = 4V_P$
$V_{out} = 4$(1186.6 V)
$V_{out} = 4746.4$ V

Answer: The output voltage will be 4746.4 V.

CRITICAL THINKING

4-44. *Answer:* If one of the diodes shorts, it will provide a low resistance path to either blow a fuse or damage the other diodes.

4-45. *Given:*

Turns ratio = N_1/N_2 = 8: 1 = 8
$V_1 = 120$ V ac

Solution:

$V_2 = V_1/(N_1/N_2)$ (Eq. 4-5)
$V_2 = 120$ V ac/8
$V_2 = 15$ V ac

$V_P = 1.414\ V_{rms}$
$V_P = 1.414$ (15 V ac)
$V_P = 21.21$ V

Since each resistor is in the same current path and both have the same value, they equally divide the voltage. Since they both have a capacitor input filter, they divide the peak voltage.

Answer: Each power supply has 10.6 V, but the load connected to the right side of the bridge is a positive 10.6 V and the load connected to the left side is a negative 10.6 V.

4-46. *Given:*

$V_P = 21.21\ V_P$ from Prob. 4-1
$R = 4.7\ \Omega$

Solution: The maximum surge current would be all of the peak voltage dropped across the resistor.

$I = V/R$ (Ohm's law)
$I = 21.21\ \text{V}/4.7\ \Omega$
$I = 4.51$ A

Answer: The maximum surge current will be 4.51 A.

4-47. *Answer:* The signal is a sine wave, and thus the shape of the curve is a function of sine. The formula for the instantaneous voltage at any point on the curve is $V = V_p\sin\theta$. Using this formula, calculate the values for each point on the curve, add all 180 of the 1° points together and divide by 180.

4-48. *Given:*

Turns ratio = N_1/N_2 = 8:1 = 8
$V_1 = 120$ V ac

Solution:

$V_2 = V_1/(N_1/N_2)$ (Eq. 4-5)
$V_2 = 120$ V ac/8
$V_2 = 15$ V ac

$V_P = 1.414\ V_{rms}$
$V_P = 1.414$ (15 V ac)
$V_P = 21.21$ V

With the switch in the shown position, it is a bridge rectifier with a capacitor input filter. Thus the output voltage would be 21.21 V.

With the switch in the other position, it is a full-wave rectifier with a capacitor input filter. Since it is a center-tapped transformer, the peak voltage is half.

$V_P = 10.6\ V_P$

The output would be 10.6 V.

Answer: With the switch in the shown position, 21.21 V; with the switch in the other position, 10.6 V.

4-49. *Answer:* Both capacitors will charge to approximately 56 mV with opposite polarities. V_{out} will equal 56 mV – 56 mV. V_{out} will equal zero volts.

4-50. Fault 1—Since the load voltage is 0.636 of the peak voltage, the capacitor input filter is not doing its job; thus the capacitor is bad.

Fault 2—Since the load voltage dropped a little and the ripple doubled, one of the diodes is open; this causes the frequence of the ripple to drop to half, which in turn causes the ripple to double.

Fault 3—Since V_1 is zero, the fuse must be blown. Since the load resistance is zero, the load resistor is shorted. This caused the excessive current in the secondary, which fed back to the primary and blew the fuse.

Fault 4—Since V_2 is good and all other voltages are bad, the transformer and fuse are good. R and C are good: thus either all four diodes opened (not likely) or there is an open in the ground circuit.

Fault 5—Since V_1 is zero, the fuse must be blown.

Fault 6—The load resistor is open. No current is drawn, and thus there is no ripple.

Fault 7—Since V_1 is good and V_2 is bad, the transformer is the problem.

Fault 8—Since V_1 is zero, the fuse must be blown. Since the capacitor reads zero, the capacitor is shorted. This caused the excessive current in the secondary, which fed back to the primary and blew the fuse.

Fault 9—Since the load voltage is 0.636 of the peak voltage, the capacitor input filter is not doing its job and thus the capacitor is bad.

Chapter 5 Special-Purpose Diodes

SELF-TEST

1. d	**9. c**	**17. c**	**25. b**
2. b	**10. b**	**18. c**	**26. d**
3. b	**11. c**	**19. b**	**27. a**
4. a	**12. a**	**20. b**	**28. c**
5. a	**13. b**	**21. a**	**29. b**
6. c	**14. d**	**22. c**	**30. b**
7. c	**15. d**	**23. c**	**31. d**
8. a	**16. a**	**24. c**	**32. a**

JOB INTERVIEW QUESTIONS

3. The zener regulation is dropping out of regulation during worst-case conditions of low line voltage and high load current.

4. The LED is connected backward, or the LED current is excessive either because the series resistor is too small or the driving voltage is too high.

5. The basic idea is that a varactor is a voltage-controlled capacitance. By using a varactor as part of an *LC* tank circuit, we can control the resonant frequency with a dc voltage.

6. To provide a high degree of electrical isolation between input and output circuits.

7. The cathode lead is shorter than the anode lead. Also, the flat side of the dome package is the cathode.

PROBLEMS

5-1. *Given:*

$V_S = 24$ V
$V_Z = 15$ V
$R_S = 470\ \Omega$

Solution:

$I_S = I_Z = (V_S - V_Z)/R_S$ (Eq. 5-3)
$I_S = I_Z = (24\text{ V} - 15\text{ V})/)470\ \Omega)$
$I_S = I_Z = 19.1$ mA

Answer: The zener current is 19.1 mA.

5-2. *Given:*

$V_S = 40$ V
$V_Z = 15$ V
$R_S = 470\ \Omega$

Solution:

$I_S = I_Z = (V_S - V_Z)/R_S$ (Eq. 5-3)
$I_Z = (40\text{ V} - 15\text{ V})/470\ \Omega$
$I_Z = 53.2$ mA

Answer: The maximum zener current is 53.2 mA.

5-3. *Given:*

$V_S = 24$ V
$V_Z = 15$ V
$R_S = 470\ \Omega \pm 5\%$
$R_{S(\text{max})} = 493.5\ \Omega$
$R_{S(\text{min})} = 446.5\ \Omega$

Solution:

$I_S = I_{Z(\text{max})} = (V_S - V_Z)/R_{S(\text{min})}$ (Eq. 5-3)
$I_S = I_Z = (24\text{ V} - 15\text{ V})/(446.5\ \Omega)$
$I_S = I_Z = 20.16$ mA

Answer: The maximum zener current is 20.16mA.

5-4. *Given:*

$V_S = 24$ V
$V_Z = 15$ V
$R_S = 470\ \Omega$
$R_L = 15\text{ k}\Omega$

Solution:

$V_L = [R_L/(R_S + R_L)]V_S$ (Voltage divider formula)
$V_L = [1.5\text{ k}\Omega/(470\ \Omega + 1.5\text{ k}\Omega)]24\text{ V}$
$V_L = 18.27$ V

Answer: The load voltage is 18.27 V.

5-5. *Given:*

$V_S = 24$ V
$V_Z = 15$ V
$R_S = 470\ \Omega$
$R_L = 1.5\text{ k}\Omega$

Solution:

$I_S = (V_S - V_Z)/R_S$ (Eq. 5-3)
$I_S = (24\text{ V} - 15\text{ V})/470\ \Omega$
$I_S = 19.15$ mA

$I_L = V_L/R_L$ (Eq. 5-5, Ohm's law)
$I_L = 15\text{ V}/1.5\text{ k}\Omega$
$I_L = 10$ mA

$I_Z = I_S - I_L$ (Eq. 5-6, Kirchhoff's current law)
$I_Z = 19.15\text{ mA} - 10\text{ mA}$
$I_Z = 9.15$ mA

Answer: The series current is 19.15 mA, the zener current is 9.15 mA, and the load current is 10 mA.

5-6. *Given:*

$V_S = 24$ V
$V_Z = 15$ V
$R_S = 470\ \Omega \pm 5\%$
$R_{S(\text{max})} = 493.5\ \Omega$
$R_{S(\text{min})} = 446.5\ \Omega$
$R_L = 1.5\text{ k}\Omega$
$R_{L(\text{max})} = 1.575\text{ k}\Omega$
$R_{L(\text{min})} = 1.425\text{ k}\Omega$

Solution: Looking at Eq. (5-6), the maximum zener current would occur at a maximum series current and a minimum load current. To achieve these conditions, the series resistance would have to be minimum and the load resistance would have to be maximum.

$I_S = (V_S - V_Z)/R_{S(\text{min})}$ (Eq. 5-3)
$I_S = (24\text{ V} - 15\text{ V})/446.5\ \Omega$
$I_S = 20.16$ mA

$I_L = V_L/R_{L(\text{max})}$ (Eq. 5-5. Ohm's law)
$I_L = 15\text{ V}/1.575\text{ k}\Omega$
$I_L = 9.52$ mA

$I_Z = I_S - I_L$ (Eq. 5-6, Kirchhoff's current law)
$I_Z = 20.16\text{ mA} - 9.52\text{ mA}$
$I_Z = 10.64$ mA

Answer: The maximum zener current is 10.64 mA.

5-7. *Given:*

$V_S = 24$ V to 40 V
$V_Z = 15$ V
$R_S = 470\ \Omega$

Solution: Maximum current will occur at maximum voltage.

$I_S = (V_S - V_Z)/R_S$ (Eq. 5-3)
$I_S = (40\text{ V} - 15\text{ V})/470\ \Omega$
$I_S = 53.2$ mA

$I_L = V_L/R_L$ (Eq. 5-5, Ohm's law)
$I_L = 15\text{ V}/1.5\text{ k}\Omega$
$I_L = 10$ mA

$I_Z = I_S - I_L$ (Eq. 5.6, Kirchhoff's current law)
$I_Z = 53.2 \text{ mA} - 10 \text{ mA}$
$I_Z = 43.2 \text{ mA}$

Answer: The maximum zener current is 43.2 mA.

5-8. *Given:*

$V_S = 24$ V
$V_Z = 12$ V
$R_S = 470\ \Omega$
$R_L = 1.5\ \text{k}\Omega$

Solution:

$V_L = V_Z = 12$ V

$I_S = (V_S - V_Z)/R_S$ (Eq. 5-3)
$I_S = (24 \text{ V} - 12 \text{ V})/470\ \Omega$
$I_S = 25.5$ mA

$I_L = V_L/R_L$ (Eq. 5-5, Ohm's law)
$I_L = 12 \text{ V}/1.5\ \text{k}\Omega$
$I_L = 8$ mA

$I_Z = I_S - I_L$ (Eq. 5-6, Kirchhoff's current law)
$I_Z = 25.5 \text{ mA} - 8 \text{ mA}$
$I_Z = 17.5$ mA

Answer: The load voltage is 12 V and the zener current is 17.5 mA.

5-9. *Given:*

$V_S = 20$ V
$V_Z = 12$ V
$R_S = 330\ \Omega$
$R_L = 1\ \text{k}\Omega$

Solution:

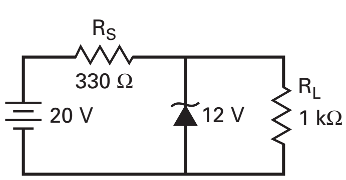
$V_L = V_Z = 12$ V

$I_S = (V_S - V_Z)/R_S$ (Eq. 5-3)
$I_S = (20 \text{ V} - 12 \text{ V})/330\ \Omega$
$I_S = 24.24$ mA

$I_L = V_L/R_L$ (Eq. 5-5, Ohm's law)
$I_L = 12 \text{ V}/1\ \text{k}\Omega$
$I_L = 12$ mA

$I_Z = I_S - I_L$ (Eq. 5-6, Kirchhoff's current law)
$I_Z = 24.24 \text{ mA} - 12 \text{ mA}$
$I_Z = 12.24$ mA

Answer: The load voltage is 12 V, and the zener current is 12.24 mA.



Zener regulator for Prob. 5-9.

5-10. *Given:*

$R_S = 470\ \Omega$
$R_Z = 14\ \Omega$
$V_{R(\text{in})} = 1$ Vpp

Solution:

$V_{R(\text{out})} = \frac{R_Z}{R_S} V_{R(\text{in})}$ (Eq. 5-8)
$V_{R(\text{out})} = (14\ \Omega/470\ \Omega)/1$ Vpp
$V_{R(\text{out})} = 29.8$ mVpp

Answer: The ripple voltage across the load resistor is 29.8 mVpp.

5-11. *Given:*

$V_S = 21.5$ to 25 V
$R_S = 470\ \Omega$
$R_Z = 14\ \Omega$
$V_Z = 15$ V

Solution:

$I_S = (V_S - V_Z)/R_S$ (Eq. 5-3)
$I_S = (25 \text{ V} - 15 \text{ V})/470\ \Omega$
$I_S = 21.28$ mA

$I_L = V_L/R_L$ (Eq. 5-5, Ohm's law)
$I_L = 15 \text{ V}/1.5\ \text{k}\Omega$
$I_L = 10$ mA

$I_Z = I_S - I_L$ (Eq. 5-6, Kirchhoff's current law)
$I_Z = 21.28 \text{ mA} - 10 \text{ mA}$
$I_Z = 11.28$ mA

$\Delta V_L = I_Z R_Z$ (Eq. 5-7)
$\Delta V_L = (11.28 \text{ mA})(14\ \Omega)$
$\Delta V_L = 157.9$ mV

$I_S = (V_S - V_Z)/R_S$ (Eq. 5-3)
$I_S = (21.5 \text{ V} - 15 \text{ V})/470\ \Omega$
$I_S = 13.83$ mA

$I_L = V_L/R_L$ (Eq. 5-5, Ohm's law)
$I_L = 15 \text{ V}/1.5\ \text{k}\Omega$
$I_L = 10$ mA

$I_Z = I_S - I_L$ (Eq. 5-6, Kirchhoff's current law)
$I_Z = 13.83 \text{ mA} - 10 \text{ mA}$
$I_Z = 3.83$ mA

$\Delta V_L = I_Z R_Z$ (Eq. 5-7)
$\Delta V_L = (3.83 \text{ mA})(14\Omega)$
$\Delta V_L = 53.6$ mV

Answer: The load voltage changes from 15.054 V when the supply is 21.5 V, to 15.158 V when the supply is 25 V.

5-12. *Given:*

$V_S = 24$ V
$R_S = 470\ \Omega$
$R_L = 1.5\ \text{k}\Omega$
$V_Z = 15$ V

Solution: The regulation is lost once the load voltage drops below 15 V.

$V_L = [(R_L)/(R_S + R_L)]V_S$ (Voltage divider formula)
$V_S = V_L/[R_L/(R_S + R_L)]$
$V_S = 15 \text{ V}[(1.5\ \text{k}\Omega)/(470\ \Omega + 1.5\ \text{k}\Omega)]$
$V_S = 19.7$ V

Answer: The regulation will be lost when the source voltage drops below 19.7 V.

5-13. *Given:*

$V_S = 20$ to 26 V
$R_S = 470\ \Omega$
$R_L = 500$ to $1.5\ \text{k}\Omega$
$V_Z = 15$ V

Solution: The regulation is lost once the load voltage drops below 15 V.

$I_L = V_L/R_L$ (Eq. 5-5, Ohm's law)
$I_L = 15 \text{ V}/1.5\ \text{k}\Omega$

$R_{S(\max)} = [(V_{S(\min)}/V_Z) - 1]R_{L(\min)}$ (Eq. 5-9)
$R_{S(\max)} = [(20 \text{ V}/15 \text{ V}) - 1]500\ \Omega$
$R_{S(\max)} = 167\ \Omega$

Answer: The regulator will fail since the series resistor is greater than the maximum series resistance. For this regulator to work properly, the series resistor should be 167 Ω or less.

5-14. *Given:*

V_S = 18 to 25 V
R_S = 470 Ω
I_L = 1 to 25 mA
V_Z = 15 V

Solution:

$R_{S(\max)} = \left[\frac{V_{S(\min)} - V_Z}{I_{L(\max)}}\right] R_{L(\min)}$ (Eq. 5-10)
$R_{S(\max)}$ = [(18 V – 15V)/25 mA
$R_{S(\max)}$ = 120 Ω

Answer: Yes, the regulator will fail since the series resistance is greater than the maximum series resistance. For this regulator to work properly, the series resistor should be 120 Ω or less.

5-15. *Given:*

V_S = 24 V
R_S = 470 Ω
V_Z = 15 V

Solution:

$R_{S(\max)} = [(V_{S(\min)}/V_Z) - 1]R_{L(\min)}$ (Eq. 5-9)
$R_{L(\min)} = R_{S(\max)}/[(V_{S(\min)}/V_Z) - 1]$
$R_{L(\min)}$ = 470 Ω/[(24 V/15 V) – 1]
$R_{L(\min)}$ = 783 Ω

Answer: The minimum load resistance is 783 Ω.

5-16. *Given:*

V_Z = 10 V
I_Z = 20 mA

Solution:

$P_Z = V_Z I_Z$ (Eq. 5-11)
P_Z = (10 V)(20 mA)
P_Z = 0.2 W

Answer: The power dissipation is 0.2 W.

5-17. *Given:*

V_Z = 20 V
I_Z = 5 mA

Solution:

$P_Z = V_Z I_Z$ (Eq. 5-11)
P_Z = (20 V)(5 mA)
P_Z = 0.1 W

Answer: The power dissipation is 0.1 W.

5-18. *Given:*

V_S = 24 V
R_S = 470 Ω
R_L = 1.5 kΩ
V_Z = 15 V
I_S = 19.15 mA (from Prob. 5-5)
I_L = 10 mA (from Prob. 5-5)
V_Z = 9.15 mA (from Prob. 5-5)

Solution:

$P = I^2R$
P_S = (19.15 mA)^2(470Ω)
P_S = 172.4 mW

$P = I^2R$
P_L = (10 mA)^2(1.5 kΩ)
P_L = 150 mW

$P_Z = VI$
P_Z = (15 V)(9.15 mA)
P_Z = 137.3 mW

Answer: The power dissipation of the series resistor is 172.4 mW. The power dissipation of the load resistor is 150 mW. The power dissipation of the zener diode is 137.3 mW.

5-19. *Given:* V_Z = 15 V ± 5%. The tolerance is in note 1 on the data sheet.

Solution:

(15 V)(0.05) = 0.75 V
15 V + 0.75 V = 15.75 V
15 V – 0.75 V = 14.25 V

Answer: The minimum voltage of 14.25 V and the maximum voltage is 15.75 V.

5-20. *Given:*

T = 100°C

Solution:

100°C – 50°C = 50°C
Derating factor 6.67 mW/°C

Answer: P = 667 mW

5-21. *Given:*

V_S = 24 V
R_S = 470 Ω
R_L = 1.5 kΩ
R_Z = 15 V

Solutions:

a. With the diode in parallel with the load, the load resistor is also effectively shorted and the output voltage would be 0 V.
b. With the diode open, the load resistor and the series resistor form a voltage divider:
$V_L = [R_L/(R_S + R_L)]V_S$ (Voltage divider formula)
V_L = [1.5 kΩ/(470 Ω + 1.5 kΩ)]24 V
V_L = 18.27 V
c. With the series resistor open, no voltage reaches the load; thus the output voltage would be 0 V.
d. The voltage drop across a short is 0 V.

Answers:

a. 0 V
b. 18.27 V
c. 0 V
d. 0 V

5-22. *Answer:* From the previous problem, the only trouble that caused this symptom is an open zener diode.

5-23. *Answer:* Check the series resistor. If it is shorted, it could damage the diode. If it had been operating correctly, the output voltage should have been 18.3 V.

5-24. *Answers:*

a. If the V130LA2 is open, it will remove the over voltage protection and the LED will remain lit.
b. If the ground is opened, there is no path for current and thus the LED will not be lit.
c. If the filler capacitor is open, the voltage will have more ripple but the LED should remain lit.
d. If the filter capacitor is shorted, the voltage across all devices in parallel with it will be zero; thus the LED will not be lit.
e. If the 1N5314 is open, it will have no effect on the LED.

f. If the 1N5314 is shorted, the voltage across all devices in parallel with it will be zero; thus the LED will not be lit.

5-25. *Given:*

$V_S = 15$ V
$V_D = 2$ V
$R_S = 2.2$ kΩ

Solution:

$I_S = (V_S - V_D)/R_S$ (Eq. 5-13)
$I_S = (15 \text{ V} - 2 \text{ V})/2.2 \text{ k}\Omega$
$I_S = 5.91$ mA

Answer: The diode current is 5.91 mA.

5-26. *Given:*

$V_S = 40$ V.
$V_D = 2$ V
$R_S = 2.2$ kΩ

Solution:

$I_S = (V_S - V_D)/R_S$ (Eq. 5-13)
$I_S = (40 \text{ V} - 2 \text{ V})/2.2 \text{ k}\Omega$
$I_S = 17.27$ mA

Answer: The diode current is 17.27 mA.

5-27. *Given:*

$V_S = 15$ V
$V_D = 2$ V
$R_S = 1$ kΩ

Solution:

$I_S = (V_S - V_D)/R_S$ (Eq. 5-13)
$I_S = (15 \text{ V} - 2 \text{ V})/1 \text{ k}\Omega$
$I_S = 13$ mA

Answer: The diode current is 13 mA.

5-28. *Answer:* From Prob. 5-27, the resistor value will be 1 kΩ.

CRITICAL THINKING

5-29. *Given:*

$V_S = 24$ V
$R_S = 470$ Ω
$R_Z = 14$ Ω
$V_Z = 15$ V

Solution:

$I_S = (V_S - V_Z)/R_S$ (Eq. 5-3)
$I_S = (24 - 15)/470$ Ω
$I_S = 19.15$ mA

$I_L = V_L/R_L$ (Eq. 5-5, Ohm's law)
$I_L = 15 \text{ V}/1.5 \text{ k}\Omega$
$I_L = 10$ mA
$I_Z = I_S - I_L$ (Eq. 5-6, Kirchhoff's current law)
$I_Z = 19.15 \text{ mA} - 10 \text{ mA}$
$I_Z = 9.15$ mA

$\Delta V_L = I_Z R_Z$ (Eq. 5-7)
$\Delta V_L = (9.15 \text{ mA})(14\ \Omega)$
$\Delta V_L = 128.1$ mV

$V_L = 15.128$ V or approximately 15.13 V

Answer: The load voltage would be 15.13 V.

5-30. *Given:*

$V_S = 24$ V
$R_S = 470$ Ω
$R_Z = 14$ Ω
$V_Z = 15$ V
$R_L = 1$ kΩ to 10 kΩ
$I_S = 19.15$ mA (from Prob. 5-29)

Solution:

$I_{L(\max)} = V_L/R_{L(\min)}$ (Eq. 5-5, Ohm's law)
$I_{L(\max)} = 15 \text{ V}/1 \text{ k}\Omega$
$I_{L(\max)} = 15$ mA

$I_{L(\min)} = V_L/R_{L(\max)}$ (Eq. 5-5, Ohm's law)
$I_{L(\min)} = 15 \text{ V}/10 \text{ k}\Omega$
$I_{L(\min)} = 1.5$ mA

$I_{Z(\min)} = I_S - I_{L(\max)}$ (Eq. 5-6, Kirchhoff's current law)
$I_{Z(\min)} = 19.15 \text{ mA} - 15 \text{ mA}$
$I_{Z(\min)} = 4.15$ mA

$I_{Z(\max)} = I_S - I_{L(\min)}$ (Eq. 5-6, Kirchhoff's current law)
$I_{Z(\max)} = 19.15 \text{ mA} - 1.5 \text{ mA}$
$I_{Z(\max)} = 17.65$ mA

$\Delta V_{L(\min)} = I_{Z(\min)} R_Z$
$\Delta V_{L(\min)} = (4.15 \text{ mA})(14\ \Omega)$
$\Delta V_{L(\min)} = 58.1$ mV

$\Delta V_{L(\max)} = I_{Z(\max)} R_Z$
$\Delta V_{L(\max)} = (17.65 \text{ mA})(14\ \Omega)$
$\Delta V_{L(\max)} = 247.1$ mV

$V_{L(\min)} = 15.058$ V
$V_{L(\max)} = 15.247$ V

Answer: The minimum load voltage would be 15.06 V and the maximum voltage would be 15.25 V.

5-31. *Given:*

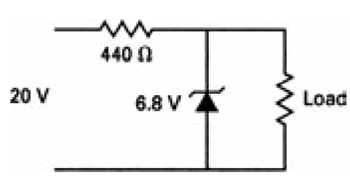
$V_S = 20$ V
$V_Z = 6.8$ V
$V_L = 6.8$ V
$I_L = 30$ mA

Solution:

$R_{S(\max)} = [(V_{S(\min)} - V_Z)/I_{L(\max)}]$ (Eq. 5-10)
$R_{S(\max)} = [(20 \text{ V} - 6.8 \text{ V})/30 \text{ mA}]$
$R_{S(\max)} = 440$ Ω

$R_{S(\min)} = [(V_S - V_Z)/I_{ZM}]$
$R_{S(\min)} = [(20 \text{ V} - 6.8 \text{ V})/55 \text{ mA}]$
$R_{S(\min)} = 240$ Ω

Answer: Any similar design as long as the zener voltage is 6.8 V and the series resistance is less than 440 Ω, to provide the desired maximum output current, and greater than 240 Ω, if a 1N957B is used to prevent overcurrent if it becomes unloaded. The load resistance does not need to be specified because, as a power supply, the load resistance can vary. The only load parameter that is necessary is maximum current, and it is given.



Zener regulator for Prob. 5-31.

5-32. *Given:* $V_{\text{LED}} = 1.5$ to 2 V

$I_{\text{LED}} = 20$ mA
$V_S = 5$ V
$I_{\max} = 140$ mA

Solution:

$R_S = [(V_S - V_{LED(min)})/I_{LED}]$
$R_S = [(5\text{ V} - 1.5\text{ V})/20\text{ mA}]$
$R_S = 175\ \Omega$

Answer: Same as Fig. 5-20 with resistor values of 175 Ω, which limits each branch to a maximum of 20 mA and a total of 140 mA.

5-33. *Given:*

$V_{line} = 115\text{ V ac} \pm 10\%$
$V_{Sec} = 12.6\text{ V ac}$
$R_2 = 560\ \Omega \pm 5\%$
$R_Z = 7\ \Omega$
$V_Z = 5.1\text{ V} \pm 5\%$

Solution: To find the maximum zener current, the maximum secondary voltage, the minimum zener voltage, and the minimum resistance of R_2 must be found. If the line voltage varies by 10 percent, the secondary voltage should also vary by 10 percent.

$V_{Sec(max)} = V_{Sec} + V_{Sec}\ (10\%)$
$V_{Sec(max)} = 12.6\text{ V ac} + 12.6\text{ V ac}\ (10\%)$
$V_{Sec(max)} = 13.86\text{ V ac}$

$V_P = 1.414\text{ V ac}$
$V_P = 1.414\ (13.86\text{ V ac})$
$V_P = 19.6\text{ V}$

$V_Z = 5.1\text{ V} \pm 5\%$
$V_Z = 5.1\text{ V} - [(5.1\text{ V})\ (5\%)]$
$V_Z = 4.85\text{ V}$

$R_2 = 560\ \Omega \pm 5\%$
$R_2 = 560\ \Omega - [(560\ \Omega)\ (5\%)]$
$R_2 = 532\ \Omega$

The circuit can be visualized as a series circuit with a 19.6 V power supply, a 532 Ω R_2, a 7 Ω R_Z, and a 4.85 V zener diode.

$I_S = (V_S - V_Z)/R_S + R_Z)$ (Eq. 5-13)
$I_S = (19.6\text{ V} - 4.85\text{ V})/(532\ \Omega + 7\ \Omega)$
$I_S = 27.37\text{ mA}$

Answer: The maximum diode current is 27.37 mA.

5-34. *Given:*

$V_{Sec} = 12.6\text{ V ac}$
$V_D = 0.7\text{ V}$
$I_{1N5314} = 4.7\text{ mA}$
$I_{LED} = 15.6\text{ mA}$
$I_Z = 21.7\text{ mA}$
$C = 1000\ \mu\text{F} \pm 20\%$
$f_{in} = 60\text{ Hz}$

Solution: The dc load current is the sum of all of the loads.

$I = I_{1N5314} + I_{LED} + I_Z$
$I = 4.7\text{ mA} + 15.6\text{ mA} + 21.7\text{ mA}$
$I = 42\text{ mA}$

$f_{out} = 2f_{in}$ (Eq. 4-7)
$f_{out} = 2(60\text{ Hz})$
$f_{out} = 120\text{ Hz}$

The minimum capacitance will give the maximum ripple.

$C = 1000\ \mu\text{F} \pm 20\%$
$C = 1000\ \mu\text{F} - 1000\ \mu\text{F}\ (20\%)$
$C = 800\ \mu\text{F}$

$V_R = I/(fC)$ (Eq. 4-10)
$V_R = 42\text{ mA}/(120\text{ Hz})(800\ \mu\text{F})$
$V_R = 0.438\text{ V}$

Answer: The maximum ripple voltage will be 0.438 V.

5-35. *Given:*

$V_S = 6\text{ V ac}$
$V_D = 0.25\text{ V}$

Solution:

$V_{P(in)} = 1.414\ V_{rms}$
$V_{P(in)} = 1.414\ (6\text{ V ac})$
$V_{P(in)} = 8.48\ V$
$V_{P(out)} = V_{P(in)} - 0.5\text{ V}$ (Eq. 4-8; the 1.4 was changed to reflect using Schottky diodes)
$V_{P(out)} = 7.98\text{ V}$

Answer: The voltage at the filter capacitor is 7.98 V.

5-36. *Troubles:*

1. Open R_S, since there is voltage at *A* and no voltage at *B*; also could be a short from *B* or *C* to ground.
2. Open between *B* and *D* or an open at *E*. Since the voltages at *B* and *C* are 14.2 V, which is the voltage that would be present if the circuit were just a voltage divider with no zener diode, suspect something in the diode circuit. Since the diode is good, it is either an open between *B* and *D* or an open at *E*.
3. The zener is open. Since the voltages at *B* and *C* are 14.2 V, which is the voltage that would be present if the circuit were just a voltage divider with no zener diode, suspect something in the diode circuit. Since the diode reads an open, it is bad.
4. R_S shorted, which caused the zener to open. With all the voltages at 18 V, the problem could be an open in the return path. But the zener is open, and the most likely cause of that is overcurrent. The only device that could short and cause the zener to burn open is R_S.

5-37. *Troubles:*

5. Open at *A*. Since all the voltages are zero, the power must not be getting to the circuit.
6. Open R_L, an open between *B* and *C*, or an open between R_L and ground. To solve this problem, the second approximation must be used. With the load resistor operating normally, only part of the total current flows through the zener, which causes the 0.3-V increase from its nominal voltage. But when the load resistor opens, all the total current flows through the diode, causing the voltage drop across the internal resistance to increase to 0.5 V.
7. Open at *E*. Since the voltages at *B*, *C*, and *D* are 14.2 V, which is the voltage that would be present if the circuit were just a voltage divider with no zener diode, suspect something in the diode circuit. Since the diode reads OK, that only leaves an open in the return path.
8. The zener is shorted or a short from *B*, *C*, or *D* to ground. Since the voltages at *B*, *C*, and *D* are 0, and *A* is 18 V, this could be caused by an open R_S or a short from *B*, *C*, or *D* to ground. Since the diode reads 0 Ω, it confirms that the fault is a short.

Chapter 6 Bipolar Transistors

SELF-TEST

1. b	**9. b**	**17. d**	**25. a**
2. a	**10. a**	**18. b**	**26. c**
3. d	**11. a**	**19. a**	**27. d**
4. a	**12. b**	**20. a**	**28. c**
5. c	**13. d**	**21. b**	**29. a**
6. a	**14. b**	**22. b**	**30. a**
7. b	**15. a**	**23. b**	
8. b	**16. b**	**24. c**	

JOB INTERVIEW QUESTIONS

6. A transistor or semiconductor curve tracer.
7. Since there is almost zero power dissipation at saturation and cutoff, I would expect that the maximum power dissipation is in the middle of the load line.
10. Common emitter.

PROBLEMS

6-1. *Given:*

$I_E = 10$ mA
$I_C = 9.95$ mA

Solution:

$I_E = I_C + I_B$ (Eq. 6-1)
$I_B = I_E - I_C$
$I_B = 10$ mA – 9.95 mA
$I_B = 0.05$ mA

Answer: The base current is 0.05 mA.

6-2. *Given:*

$I_C = 10$ mA
$I_B = 0.1$ mA

Solution:

$\beta_{dc} = I_C/I_B$
$\beta_{dc} = 10$ mA/0.1 mA
$\beta_{dc} = 100$

Answer: The current gain is 100.

6-3. *Given:*

$I_B = 30$ µA
$\beta_{dc} = 150$

Solution:

$I_C = \beta_{dc} I_B$
$I_C = 150(30$ µA)
$I_C = 4.5$ mA

Answer: The collector current is 4.5 mA.

6-4. *Given:*

$I_C = 100$ mA
$\beta_{dc} = 65$

Solution:

$I_B = I_C/\beta_{dc}$ (Eq. 6-5)
$I_B = 100$ mA/65
$I_B = 1.54$ mA
$I_E = I_B + I_C$
$I_E = 1.54$ mA + 100 mA

Answer: The emitter current is 101.54 mA.

6-5. *Given:*

$V_{BB} = 10$ V
$R_B = 470$ kΩ
$V_{BE} = 0.7$ V

Solution:

$I_B = [(V_{BB} - V_{BE})/R_B]$ (Eq. 6-6)
$I_B = [(10$ V – 0.7 V)/470 kΩ]
$I_B = 19.8$ µA

Answer: The base current is 19.8 µA.

6-6. *Answer:* The base current is unaffected by the current gain since 9.3 V/470 kΩ always equals 19.8 µA. The current gain will affect the collector current in this circuit.

6-7. *Given:*

$V_{BB} = 10$ V
$R_B = 470$ kΩ ± 5%
$V_{BE} = 0.7$ V

Solution:

The minimum resistance will yield the maximum current.

$R_B = 470$ kΩ ± 5%
$R_B = 470$ kΩ – 470 kΩ(5%)
$R_B = 446.5$ kΩ

$I_B = [(V_{BB} - V_{BE})/R_B]$ (Eq. 6-6)
$I_B = [(10$ V – 0.7 V)/446.5 kΩ]
$I_B = 20.83$ µA

Answer: The base current is 20.83 µA.

6-8. *Given:*

$I_C = 6$ mA
$R_C = 1.5$ kΩ
$V_{CC} = 20$ V

Solution:

$V_{CE} = V_{CC} - I_C R_C$
$V_{CE} = 20$ V – (6 mA)(1.5 kΩ)
$V_{CE} = 11$ V

Answer: The collector to emitter voltage is 11 V.

6-9. *Given:*

$I_C = 100$ mA
$V_{CE} = 3.5$ V

Solution:

$P_D = V_{CE} I_C$ (Eq. 6-8)
$P_D = (3.5$ V)(100 mA)
$P_D = 350$ mW

Answer: The power dissipation is 350 mW.

6-10. *Given:*

$V_{BB} = 10$ V
$R_B = 470$ kΩ
$V_{BE} = 0.7$ V (second approximation)
$V_{BE} = 0$ V (ideal)
$R_C = 820$ Ω
$V_{CC} = 10$ V
$\beta_{dc} = 200$

Solution:

Ideal
$I_B = [(V_{BB} - V_{BE})/R_B]$ (Eq. 6-6)
$I_B = [(10$ V – 0 V)/470 kΩ]
$I_B = 21.28$ µA

$I_C = \beta_{dc} I_B$
$I_C = 200(21.28$ µA)
$I_C = 4.26$ mA

$V_{CE} = V_{CC} - I_C R_C$
$V_{CE} = 10$ V – (4.26 mA)(820 Ω)
$V_{CE} = 6.5$ V

$P_D = V_{CE} I_C$
$P_D = (6.5$ V)(4.26 mA)
$P_D = 27.69$ mW

2nd Approximation

$I_B = [(V_{BB} - V_{BE})/R_B]$ (Eq. 6-6)
$I_B = [(10$V – 0.7 V)/470 kΩ]
$I_B = 19.8$ µA

$I_C = \beta_{dc} I_B$
$I_C = 200(19.8$ µA)
$I_C = 3.96$ mA

$V_{CE} = V_{CC} - I_C R_C$
$V_{CE} = 10\text{ V} - (3.96\text{ mA})(820\ \Omega)$
$V_{CE} = 6.75\text{ V}$

$P_D = V_{CE} I_C$
$P_D = (6.75\text{ V})(3.96\text{ mA})$
$P_D = 26.73\text{ mW}$

Answer: The ideal collector-emitter voltage is 6.5 V and power dissipation is 27.69 mW. The second approximation collector-emitter voltage is 6.75 V and the power dissipation is 26.73 mW.

6-11. *Given:*

$V_{BB} = 5\text{ V}$
$R_B = 330\text{ k}\Omega$
$V_{BE} = 0.7\text{ V}$ (second approximation)
$V_{BE} = 0\text{ V}$ (ideal)
$R_C = 1.2\text{ k}\Omega$
$V_{CC} = 15\text{ V}$
$\beta_{dc} = 150$

Solution:

Ideal
$I_B = [(V_{BB} - V_{BE})/R_B]$ (Eq. 6-6)
$I_B = [(5\text{ V} - 0\text{ V})/330\text{ k}\Omega]$
$I_B = 15.15\ \mu\text{A}$

$I_C = \beta_{dc} I_B$
$I_C = 150(15.15\ \mu\text{A})$
$I_C = 2.27\text{ mA}$

$V_{CE} = V_{CC} - I_C R_C$
$V_{CE} = 15\text{ V} - (2.27\text{ mA})(1.2\text{ k}\Omega)$
$V_{CE} = 12.28\text{ V}$

$P_D = V_{CE} I_C$
$P_D = (12.28\text{ V})(2.27\text{ mA})$
$P_D = 27.88\text{ mW}$

2nd Approximation
$I_B = [(V_{BB} - V_{BE})/R_B]$ (Eq. 6-6)
$I_B = [(5\text{ V} - 0.7\text{ V})/330\text{ k}\Omega]$
$I_B = 13.3\ \mu\text{A}$

$I_C = \beta_{dc} I_B$
$I_C = 150(13.03\ \mu\text{A})$
$I_C = 1.96\text{ mA}$

$V_{CE} = V_{CC} - I_C R_C$
$V_{CE} = 15\text{ V} - (1.96\text{ mA})(1.2\text{ k}\Omega)$
$V_{CE} = 12.65\text{ V}$

$P_D = V_{CE} I_C$
$P_D = (12.65\text{ V})(1.96\text{ mA})$
$P_D = 24.79\text{ mW}$

Answer: The ideal collector-emitter voltage is 12.28 V and power dissipation is 27.88 mW. The second approximation collector-emitter voltage is 12.65 V, and power dissipation is 24.79 mW.

6-12. *Given:*

$V_{BB} = 12\text{ V}$
$R_B = 680\text{ k}\Omega$
$V_{BE} = 0.7\text{ V}$ (second approximation)
$V_{BE} = 0$ (ideal)
$R_C = 1.5\text{ k}\Omega$
$V_{CC} = 12\text{ V}$
$\beta_{dc} = 175$

Solution:

$I_B = [(V_{BB} - V_{BE})/R_B]$ (Eq. 6-6)
$I_B = [(12\text{ V} - 0)/680\text{ k}\Omega]$
$I_B = 17.6\ \mu\text{A}$ (ideal)

$I_B = [(12\text{ V} - 0.7\text{ V})/680\text{ k}\Omega]$
$I_B = 16.6\ \mu\text{A}$ (second approximation)

$I_C = \beta_{dc} I_B$ (Eq. 6-4)
$I_C = 175(17.6\ \mu\text{A})$
$I_C = 3.08\text{ mA}$ (ideal)

$I_C = 175(16.6\ \mu\text{A})$
$I_C = 2.91\text{ mA}$ (second approximation)

$V_{CE} = V_{CC} - I_C R_C$ (Eq. 6-7)
$V_{CE} = 12\text{ V} - (3.08\text{ mA})(1.5\text{ k}\Omega)$
$V_{CE} = 7.38\text{ V}$ (ideal)

$V_{CE} = 12\text{ V} - (2.91\text{ mA})(1.5\text{ k}\Omega)$
$V_{CE} = 7.64\text{ V}$ (second approximation)

$P_D = V_{CE} I_C$ (Eq. 6-8)
$P_D = (7.38\text{ V})(3.08\text{ mA})$
$P_D = 22.73\text{ mW}$ (ideal)

$P_D = (7.64\text{ V})(2.91\text{ mA})$
$P_D = 22.23\text{ mW}$ (second approximation)

Answer: The ideal collector-emitter voltage is 7.38 V, and power dissipation is 22.73 mW. The second approximation collector-emitter voltage is 7.64 V, and power dissipation is 22.23 mW.

6-13. *Answer:* From the maximum ratings section, –55 to + 150°C.

6-14. *Answer:* From the on characteristics section, 70.

6-15. *Given:*

$P_{D(\max)} = 1\text{ W}$
$I_C = 120\text{ mA}$
$V_{CE} = 10\text{ V}$

Solution:

$P_D = V_{CE} I_C$ (Eq. 6-8)
$P_D = (10\text{ V})(120\text{ mA})$
$P_D = 1.2\text{ W}$

Answer: The power dissipation has exceeded the maximum rating, and the transistor's power rating is damaged and possibly destroyed.

6-16. *Given:*

$P_D = 625\text{ mW}$
Temperature = 65°C

Solution:

$\Delta T = 65°C - 25°C$
$\Delta T = 40°C$

$\Delta P = \Delta T$ (derating factor)
$\Delta P = 40°C(2.8\text{ mW/°C})$
$\Delta P = 112\text{ mW}$

$P_{D(\max)} = 350\text{ mW} - 112\text{ mW}$
$P_{D(\max)} = 238\text{ mW}$

Answer: The transistor is operating outside of its limits; the power rating is affected.

6-17. **a.** Increase: With the base resistor shorted, the base-emitter junction will have excessive current and will open, stopping all conduction. Thus source voltage is read from collector to emitter.

b. Increase: With the base resistor open, the transistor goes into cutoff and source voltage is read from collector to emitter.

$P_D = V_{CE}I_C$
$I_C = P_D/V_{CE}$
$I_C = 280\ \text{mW}/10\ \text{V}$
$I_C = 28\ \text{mA}$

Answer: The maximum collector current is 28 mA.

6-23. *Given:*

$V_{BB} = 10\ \text{V}$
$R_B = 470\ \text{k}\Omega$
$V_{BE} = 0.7\ \text{V}$ (second approximation)
$R_C = 820\ \Omega$
$V_{CC} = 10\ \text{V}$
$\beta_{dc} = 200$

Solution:

$I_B = [(V_{BB} - V_{BE})/R_B]$ (Eq. 6-6)
$I_B = [(10\ \text{V} - 0.7\ \text{V})/470\ \text{k}\Omega]$
$I_B = 19.8\ \mu\text{A}$

$I_C = \beta_{dc}I_B$
$I_C = 200(19.8\ \mu\text{A})$
$I_C = 3.96\ \text{mA}$

Answer: The LED current is 3.96 mA.

6-24. *Answer:* $V_{CE(\text{Sat})} = 0.3\ \text{V}$

6-25. *Answer:* An increase in V_{BB} causes the base current to increase, and, since the transistor is controlled by base current, all other dependent variables increase except V_{CE}, which decreases because of the transistor being further into conduction.

6-26. *Answer:* The increase in V_{CC} had no effect on the base circuit, which means that it also had no effect on I_C and the voltage drop across the collector resistor. The increase did increase V_{CE} and the power dissipation across the transistor.

6-27. *Answer:* I_C, I_B, and all power dissipations decreased. The power dissipations decreased because of the drop in current ($P = IV$). The base current decreased because the voltage drop across it did not change and the resistance increased ($I = V/R$). The collector current decreased because the base current decreased ($I_C = I_B\beta_{dc}$).

6-28. *Answer:* V_A, V_B, V_D, I_B, I_C, and P_B show no change. V_A and V_D do not change since the power supply voltages did not change. I_B, V_B, and P_B do not change because the collector resistance does not affect the base circuit. I_C does not change because I_B did not change.

6-29. *Answer:* The only variable to decrease is V_C. With an increase in β_{dc}, the same base current will cause a greater collector current, which will create a greater voltage drop across the collector resistor. This leaves less voltage to drop across the transistor.

Chapter 7 Transistor Fundamentals

SELF-TEST

1. a	**9. b**	**17. d**	**25. a**
2. b	**10. a**	**18. c**	**26. c**
3. d	**11. b**	**19. b**	**27. a**
4. d	**12. c**	**20. b**	**28. b**
5. c	**13. d**	**21. b**	**29. a**
6. c	**14. c**	**22. d**	**30. d**
7. a	**15. a**	**23. b**	**31. c**
8. c	**16. b**	**24. a**	

JOB INTERVIEW QUESTIONS

7. An increase in temperature almost always increases the current gain.

10. High leakage current, low breakdown voltage, and low current gain.

12. If in cutoff, V_{CE} will be approximately equal to V_{CC}. If in saturation, V_{CE} is usually less than 1 V, typically 0.1 to 0.2 V for a small-signal transistor.

13. One with large R_C.

PROBLEMS

7-1. *Answer:* $\beta = 30$

7-2. *Answer:* $\beta = 85$

7-3. *Given:*

$V_{CC} = 20\ \text{V}$
$V_{BB} = 10\ \text{V}$
$R_B = 1\ \text{M}\Omega$
$R_C = 3.3\ \text{k}\Omega$

Solution:

$I_{C(\text{Sat})} = V_{CC}/R_C$ (Eq. 7-2)
$I_{C(\text{Sat})} = 20\ \text{V}/3.3\ \text{k}\Omega$
$I_{C(\text{Sat})} = 6.06\ \text{mA}$

$V_{CE(\text{cutoff})} = V_{CC}$ (Eq. 7-3)
$V_{CE(\text{cutoff})} = 20\ \text{V}$

Answer: The collector current at saturation is 6.06 mA, and the collector-emitter voltage at cutoff is 20 V. The load line would connect these points.

7-4. *Given:*

$V_{CC} = 25\ \text{V}$
$V_{BB} = 10\ \text{V}$
$R_B = 1\ \text{M}\Omega$
$R_C = 3.3\ \text{k}\Omega$

Solution:

$I_{C(\text{Sat})} = V_{CC}/R_C$ (Eq. 7-2)
$I_{C(\text{Sat})} = 25\ \text{V}/3.3\ \text{k}\Omega$
$I_{C(\text{Sat})} = 7.58\ \text{mA}$

Answer: The load line moves futher away from the origin.

7-5. *Given:*

$V_{CC} = 20\ \text{V}$
$V_{BB} = 10\ \text{V}$
$R_B = 1\ \text{M}\Omega$
$R_C = 4.7\ \text{k}\Omega$

Solution:

$I_{C(\text{Sat})} = V_{CC}/R_C$ (Eq. 7-2)
$I_{C(\text{Sat})} = 20\ \text{V}/4.7\ \text{k}\Omega$
$I_{C(\text{Sat})} = 4.25\ \text{mA}$

$V_{CE(\text{cutoff})} = V_{CC}$
$V_{CE(\text{cutoff})} = 20\ \text{V}$

Answer: The left side of the load line would move down while the right side remains at the same point.

7-6. *Given:*

$V_{CC} = 20\ \text{V}$
$V_{BB} = 10\ \text{V}$
$R_B = 2\ \text{M}\Omega$
$R_C = 4.7\ \text{k}\Omega$

Solution:

$I_{C(\text{Sat})} = V_{CC}/R_C$ (Eq. 7-2)
$I_{C(\text{Sat})} = 20\ \text{V}/3.3\ \text{k}\Omega$
$I_{C(\text{Sat})} = 6.06\ \text{mA}$

7-46. *Given:*

$V_{CC} = 10$ V
$V_{BB} = 5$ V
$R_E = 100\ \Omega$
$V_{BE} = 0.7$ V

Solution:

$V_E = V_{BB} - V_{BE(1)} - V_{BE(2)}$ (Eq. 7-7)
$V_E = 5\text{ V} - 0.7\text{ V} - 0.7\text{ V}$
$V_E = 3.6$ V

$I_E = V_E/R_E$ (Ohm's law)
$I_E = 3.6\text{ V}/100\ \Omega$
$I_E = 36$ mA
$I_E \approx I_C$

$I_C = 36$ mA

Answer: The collector current is 36 mA.

7-47. *Given:*

$I_C = 36$ mA (from the previous problem)
$\beta_{dc(1)} = 100$
$\beta_{dc(2)} = 50$

Solution: The overall current gain is $\beta_{dc(1)}\beta_{dc(2)}$; thus the overall current gain is (100)(50) = 5000.

$I_B = I_C/\beta_{dc}$ (Eq. 6-5)
$I_B = 36\text{ mA}/5000$
$I_B = 7.2\ \mu$A

Answer: The base current of the first transistor is 7.2 μA.

7-48. *Given:*

$V_{BB(1)} = 0$ V
$V_{BB(2)} = 10$ V
$V_{CC} = 10$ V
$R_C = 240\ \Omega$
$R_B = 2.4\text{ k}\Omega$
$R_E = 270\ \Omega$
$V_D = 5$ V
$V_{BE} = 0.7$ V

Solution: With the left transistor in cutoff, it is essentially an open. Thus the base circuit for the right transistor would consist of the zener and the resistor, and the base voltage would be 5 V.

$V_E = V_{BB} - V_{BE}$ (Eq. 7-7)
$V_E = 5\text{ V} - 0.7\text{ V}$
$V_E = 4.3$ V

$I_E = V_E/R_E$ (Ohm's law)
$I_E = 4.3\text{ V}/270\ \Omega$
$I_E = 15.93$ mA

$I_E \approx I_C = I_D$

$I_D = 15.93$ mA

With the left transistor conducting, assume an ideal transistor. The collector voltage would be 0 V, which would cause the right transistor to cutoff. Therefore, there would be no collector current and no diode current.

Answer: With V_{BB} at 0 V, the diode current is 15.93 mA, and with V_{BB} at 10 V, the diode current is 0 mA.

7-49. *Given:*

$V_{CC} = 10$ V
$V_{BB} = 0$ V
$R_B = 2.4\text{ k}\Omega$
$R_C = 240\ \Omega$
$R_E = 270\ \Omega$
$V_D = 6.8$ V
$V_{BE} = 0.7$ V

Solution: With the left transistor in cutoff, the base circuit for the right transistor would consist of the zener diode and the resistor, and the base voltage would be 6.8 V.

$V_E = V_{BB} - V_{BE}$ (Eq. 7-7)
$V_E = 6.8\text{ V} - 0.7$
$V_E = 6.1$ V

$I_E = V_E/R_E$ (Ohm's law)
$I_E = 6.1\text{ V}/270\ \Omega$
$I_E = 22.6$ mA
$I_D = I_E = 22.6$ mA

Answer: The diode current is 22.6 mA.

7-50. *Given:*

$V_{CC} = 10$ V
$R_C = 2\text{ k}\Omega$

Solution:

$I_{C(\text{Sat})} = V_{CC}/R_C$ (Eq. 7-2)
$I_{C(\text{Sat})} = 10\text{ V}/2\text{ k}\Omega$
$I_{C(\text{Sat})} = 5$ mA

Answer: The maximum possible current through the transistor is 5 mA.

7-51. *Given:*

$R_C = 2\text{ k}\Omega$
$V_{RC} = 2$ V
$R_E = 430\ \Omega$

Solution:

$I_C = V_{RC}/R_C$ (Ohm's law)
$I_C = 2\text{ V}/2\text{ k}\Omega$
$I_C = 1$ mA

$I_{\text{LED}} = 1$ mA (from the graph)
$I_{\text{LED}} = I_C = I_E$

$I_E = 1$ mA
$V_E = I_E R_E$
$V_E = (1\text{ mA})(430\ \Omega)$
$V_E = 430$ mV

$V_{BB} = V_E + V_{BE}$ (Eq. 7-8)
$V_{BB} = 0.43\text{ V} + 0.7\text{ V}$
$V_{BB} = 1.13$ V

Answer: The base voltage is 1.13 V.

7-52. *Given:*

$V_{BB} = 3$ V

$V_{BE} = 0.7$ V

Answer: Since the collector-base junction is a diode like the emitter-base junction, the internal impedance of the voltmeter will complete the circuit to ground and the collector-base diode will forward-bias. Thus the voltage will be a diode voltage drop less than the base voltage, or 2.3 V.

7-53. *Given:*

$R_B = 1\text{ M}\Omega$
$V_{BB} = 10$ V
R_C = Open

Solution:

$V_{CE} = V_{BB}$
$V_{CE} = 0.7$ V

Answer: The collector to ground voltage is approximately 0.7 V.

7-54. *Given:*

$V_{CC} = 15$ V
$V_{BB} = 0$ V and 15 V
$I_{C(\text{Sat})} = 5$ mA

Solution:

$I_{C(\text{Sat})} = V_{CC}/R_C$ (Eq. 7-2)
$R_C = V_{CC}/I_{C(\text{Sat})}$
$R_C = 15$ V/5 mA
$R_C = 3$ kΩ

$R_B = (V_{BB} - V_{BE})/I_B$
$R_B = (15$ V – 0.7)/476 μA
$R_B = 30$ kΩ

Answer: $R_C = 3$ kΩ, $R_B = 30$ kΩ

7-55. *Given:*

$V_{CC} = 10$ V
$V_{BB} = 1.8$ V
$V_{CE} = 6.6$ V
$R_E = 1$ kΩ

Solution:

$I_E = I_C = (V_{BB} - V_{BE})/R_E$
$I_E = I_C = (1.8$ V – 0.7 V)/1 kΩ
$I_E = I_C = 1.1$ mA

$V_E = I_E R_E$
$V_E = (1.1$ mA)(1 kΩ)
$V_E = 1.1$ V

$V_{RC} = V_{CC} - V_E - V_{CE}$
$V_{RC} = 10$ V – 1.1 V – 6.6V
$V_{RC} = 2.3$ V

$R_C = V_{RC}/I_C$
$R_C = 2.3$ V/1.1 mA
$R_C = 2$ kΩ

Answer: $R_C = 2$ kΩ

7-56. *Answer:* Since V_{BB} increases, the transistor's V_B and V_E values will increase along with an increase in all currents. V_C will decrease because of an increased voltage drop across R_C.

7-57. *Answer:* The increase in collector supply voltage causes an increase in collector voltage because the collector current remains constant. Thus the voltage drop across the collector resistor remains constant and the collector voltage has to increase.

7-58. *Answer:* All of the currents decrease. Since the emitter voltage remains constant, the increase in emitter resistance causes a decrease in emitter current. Since the collector current is approximately the same as the emitter current, it also decreases. The base current is related to the collector current by β_{dc} and also decreases.

7-59. *Answer:* V_B, V_E, I_E, I_C and I_B show no change. Since the base voltage did not change, V_B and V_E will not change. Since these voltages do not change, none of the currents change. V_C will decrease since the voltage drop across R_C will increase.

Chapter 8 Transistor Biasing

SELF-TEST

1. d	**9. c**	**17. b**	**24. b**
2. a	**10. a**	**18. a**	**25. b**
3. a	**11. b**	**19. d**	**26. c**
4. d	**12. a**	**20. a**	**27. b**
5. b	**13. c**	**21. c**	**28. c**
6. b	**14. c**	**22. a**	**29. a**
7. b	**15. c**	**23. d**	**30. d**
8. a	**16. a**		

JOB INTERVIEW QUESTIONS

2. The collector current changes only slightly, if at all.

4. Emitter-feedback bias and collector-feedback bias. They were developed in an attempt to stabilize the Q point against transistor replacement and temperature changes.

6. No. Saturation and cutoff.

7. Changes in current gain will change the collector current. The base resistors should be made smaller to satisfy the condition described in the text.

10. The circuit will be highly sensitive to changes in current gain.

PROBLEMS

8-1. *Given:*

$R_1 = 10$ kΩ
$R_2 = 2.2$ kΩ
$R_C = 3.6$ kΩ
$R_E = 1$ kΩ
$V_{CC} = 25$ V
$V_{BE} = 0.7$ V

Solution:

$V_{BB} = [R_2/(R_1 + R_2)]V_{CC}$ (Eq. 8-1)
$V_{BB} = [2.2$ kΩ/(10 kΩ + 2.2 kΩ)]25 V
$V_{BB} = 4.51$ V

$V_E = V_{BB} - V_{BE}$ (Eq. 8-2)
$V_E = 4.51$ V – 0.7 V
$V_E = 3.81$ V

$I_E = V_E/R_E$ (Eq. 8-3)
$I_E = 3.81$ V/1 kΩ
$I_E = 3.81$ mA

$I_C \approx I_E$ (Eq. 8-4)

$V_C = V_{CC} - I_C R_C$ (Eq. 8-5)
$V_C = 25$ V – (3.81 mA)(3.6 kΩ)
$V_C = 11.28$ V

Answer: The emitter voltage is 3.81 V, and the collector voltage is 11.28V.

8-2. *Given:*

$R_1 = 10$ kΩ
$R_2 = 2.2$ kΩ
$R_C = 2.7$ kΩ
$R_E = 1$ kΩ
$V_{CC} = 15$ V
$V_{BE} = 0.7$ V

Solution:

$V_{BB} = [R_2/(R_1 + R_2)]V_{CC}$ (Eq. 8-1)
$V_{BB} = [2.2$ kΩ/(10 kΩ + 2.2 kΩ)]15 V
$V_{BB} = 2.7$ V

$V_E = V_{BB} - V_{BE}$ (Eq. 8-2)
$V_E = 2.7$ V – 0.7 V
$V_E = 2.0$ V

$I_E = V_E/R_3$ (Eq. 8-3)
$I_E = 2.0$ V/1 kΩ
$I_E = 2$ mA

$I_C \approx I_E$ (Eq. 8-4)

$V_C = V_{CC} - I_C R_C$ (Eq. 8-5)
$V_C = 15$ V – (2 mA)(2.7 kΩ)
$V_C = 9.59$ V

Answer: The emitter voltage is 2.0 V, and the collector voltage is 9.59 V.

8-3. *Given:*

$R_1 = 330$ kΩ
$R_2 = 100$ kΩ
$R_C = 150$ kΩ
$R_E = 51$ kΩ
$V_{CC} = 10$ V
$V_{BE} = 0.7$ V

Solution:

$V_{BB} = [R_2/(R_1 + R_2)]V_{CC}$ (Eq. 8-1)
$V_{BB} = [100\ \text{k}\Omega/(330\ \text{k}\Omega + 100\ \text{k}\Omega)]10\ \text{V}$
$V_{BB} = 2.33\ \text{V}$

$V_E = V_{BB} - V_{BE}$ (Eq. 8-2)
$V_E = 2.33\ \text{V} - 0.7\ \text{V}$
$V_E = 1.63\ \text{V}$

$I_E = V_E/R_E$ (Eq. 8-3)
$I_E = 1.63\ \text{V}/51\ \text{k}\Omega$
$I_E = 31.96\ \mu\text{A}$

$I_C \approx I_E$ (Eq. 8-4)

$V_C = V_{CC} - I_C R_C$ (Eq. 8-5)
$V_C = 10\ \text{V} - (31.96\ \mu\text{A})(150\ \text{k}\Omega)$
$V_C = 5.21\ \text{V}$

Answer: The emitter voltage is 1.63 V, and the collector voltage is 5.21 V.

8-4. *Given:*

$R_1 = 150\ \Omega$
$R_2 = 33\ \Omega$
$R_C = 39\ \Omega$
$R_E = 10\ \Omega$
$V_{CC} = 12\ \text{V}$
$V_{BE} = 0.7\ \text{V}$

Solution:

$V_{BB} = [R_2/(R_1 + R_2)]V_{CC}$ (Eq. 8-1)
$V_{BB} = [33\ \Omega/(150\ \Omega + 33\ \Omega)]12\ \text{V}$
$V_{BB} = 2.16\ \text{V}$

$V_E = V_{BB} - V_{BE}$ (Eq. 8-2)
$V_E = 2.16\ \text{V} - 0.7\ \text{V}$
$V_E = 1.46\ \text{V}$

$I_E = V_E/R_E$ (Eq. 8-3)
$I_E = 1.46\ \text{V}/10\ \Omega = 146\ \text{mA}$

$I_C \approx I_E$ (Eq. 8-4)

$V_C = V_{CC} - I_C R_C$ (Eq. 8-5)
$V_C = 12\ \text{V} - (146\ \text{mA})(39\ \Omega)$
$V_C = 6.3\ \text{V}$

Answer: The emitter voltage is 1.46 V. The collector voltage is 6.3 V.

8-5. *Given:*

$R_1 = 330\ \text{k}\Omega \pm 5\%$
$R_2 = 100\ \text{k}\Omega \pm 5\%$
$R_C = 150\ \text{k}\Omega \pm 5\%$
$R_E = 51\ \text{k}\Omega \pm 5\%$
$V_{CC} = 10\ \text{V}$
$V_{BE} = 0.7\ \text{V}$

Solution:

$V_{BB(\max)} = [R_{2(\max)}/(R_{1(\min)} + R_{2(\max)})]V_{CC}$ (Eq. 8-1)
$V_{BB(\max)} = [105\ \text{k}\Omega/(313.5\ \text{k}\Omega + 105\ \text{k}\Omega)]10\ \text{V}$
$V_{BB(\max)} = 2.51\ \text{V}$

$V_{BB(\min)} = [R_{2(\min)}/(R_{1(\max)} + R_{2(\min)})]V_{CC}$ (Eq. 8-1)
$V_{BB(\min)} = [95\ \text{k}\Omega/346.5\ \text{k}\Omega + 95\ \text{k}\Omega)]10\ \text{V}$
$V_{BB(\min)} = 2.15\ \text{V}$

$V_{E(\max)} = V_{BB(\max)} - V_{BB}$ (Eq. 8-2)
$V_{E(\max)} = 2.51\ \text{V} - 0.7\ \text{V}$
$V_{E(\max)} = 1.81\ \text{V}$

$V_{E(\min)} = V_{BB(\min)} - V_{BE}$ (Eq. 8-2)
$V_{E(\min)} = 2.15\ \text{V} - 0.7\ \text{V}$
$V_{E(\min)} = 1.45\ \text{V}$

$I_{E(\max)} = V_{E(\max)}/R_{E(\min)}$ (Eq. 8-3)
$I_{E(\max)} = 1.81\ \text{V}/48.45\ \text{k}\Omega$
$I_{E(\max)} = 37.36\ \mu\text{A}$

$I_{E(\min)} = V_{E(\min)}/R_{E(\max)}$ (Eq. 8-3)
$I_{E(\min)} = 1.45\ \text{V}/53.55\ \text{k}\Omega$
$I_{E(\min)} = 27.08\ \mu\text{A}$

$I_C \approx I_E$ (Eq. 8-4)

$V_{C(\max)} = V_{CC} - I_{C(\min)}R_{C(\min)}$ (Eq. 8-5)
$V_{C(\max)} = 10\ \text{V} - (27.08\ \mu\text{A})(142.5\ \text{k}\Omega)$
$V_{C(\max)} = 6.14\ \text{V}$

$V_{C(\min)} = V_{CC} - I_{C(\max)}R_{C(\max)}$ (Eq. 8-5)
$V_{C(\min)} = 10\ \text{V} - (37.36\ \mu\text{A})(157.5\ \text{k}\Omega)$
$V_{C(\min)} = 4.12\ \text{V}$

Answer: The lowest collector voltage is 4.12 V, and the highest collector voltage is 6.14 V.

8-6. *Given:*

$R_1 = 150\ \Omega$
$R_2 = 33\ \Omega$
$R_C = 39\ \Omega$
$R_E = 10\ \Omega$
$V_{CC} = 12\ \text{V} \pm 10\%$
$V_{BE} = 0.7\ \text{V}$

Solution:

$V_{BB(\max)} = [R_2/(R_1 + R_2)]V_{CC(\max)}$ (Eq. 8-1)
$V_{BB(\max)} = [33\ \Omega/(150\ \Omega + 33\ \Omega)]13.2\ \text{V}$
$V_{BB(\max)} = 2.38\ \text{V}$

$V_{E(\max)} = V_{BB(\max)} - V_{BE}$ (Eq. 8-2)
$V_{E(\max)} = 2.38\ \text{V} - 0.7\ \text{V}$
$V_{E(\max)} = 1.68\ \text{V}$

$I_{E(\max)} = V_{E(\max)}/R_E$ (Eq. 8-3)
$I_{E(\max)} = 1.68\ \text{V}/10\ \Omega$
$I_{E(\max)} = 168\ \text{mA}$

$V_{BB(\min)} = [R_2/(R_1 + R_2)]V_{CC(\min)}$ (Eq. 8-1)
$V_{BB(\min)} = [33\ \Omega/(150\ \Omega + 33\ \Omega)]10.8\ \text{V}$
$V_{BB(\min)} = 1.95\ \text{V}$

$V_{E(\min)} = V_{BB(\min)} - V_{BE}$ (Eq. 8-2)
$V_{E(\min)} = 1.95\ \text{V} - 0.7\ \text{V}$
$V_{E(\min)} = 1.25\ \text{V}$

$I_{E(\min)} = V_{E(\min)}/R_E$ (Eq. 8-3)
$I_{E(\min)} = 1.25\ \text{V}/10\ \Omega$
$I_{E(\min)} = 125\ \text{mA}$

$I_C \approx I_E$ (Eq. 8-4)

$V_{C(\max)} = V_{CC(\max)} - I_{C(\min)}R_C$ (Eq. 8-5)
$V_{C(\max)} = 13.2\ \text{V} - (125\ \text{mA})(39\ \Omega)$
$V_{C(\max)} = 8.33\ \text{V}$

$V_{C(\min)} = V_{CC(\min)} - I_{C(\max)}R_C$ (Eq. 8-5)
$V_{C(\min)} = 10.8\ \text{V} - (168\ \text{mA})(39\ \Omega)$
$V_{C(\min)} = 4.25\ \text{V}$

Answer: The lowest collector voltage is 4.25 V and the highest collector voltage is 8.33 V.

8-7. *Given:*

$R_1 = 10\ \text{k}\Omega$
$R_2 = 2.2\ \text{k}\Omega$
$R_C = 3.6\ \text{k}\Omega$
$R_E = 1\ \text{k}\Omega$
$V_{CC} = 25\ \text{V}$
$V_{BE} = 0.7\ \text{V}$
$V_{BB} = 4.51\ \text{V}$ (from Prob. 8-1)
$V_E = 3.81\ \text{V}$ (from Prob. 8-1)
$I_E = I_C = 3.81\ \text{mA}$ (from Prob. 8-1)
$V_C = 11.28\ \text{V}$ (from Prob. 8-1)

Solution:

$V_{CE} = V_C - V_E$ (Eq. 8-6)
$V_{CE} = 11.28\ \text{V} - 3.81\ \text{V}$
$V_{CE} = 7.47\ \text{V}$

Answer: The Q point is $I_C = 3.81\ \text{mA}$, and $V_{CE} = 7.47\ \text{V}$.

8-8. *Given:*

$R_1 = 10\ k\Omega$
$R_2 = 2.2\ k\Omega$
$R_C = 2.7\ k\Omega$
$R_E = 1\ k\Omega$
$V_{CC} = 15\ V$
$V_{BE} = 0.7\ V$

Solution:

$V_{BB} = [R_2/(R_1 + R_2)]V_{CC}$ (Eq. 8-1)
$V_{BB} = [2.2\ k\Omega/(10\ \Omega + 2.2\ k\Omega)]15\ V$
$V_{BB} = 2.7\ V$

$V_E = V_{BB} - V_{BE}$ (Eq. 8-2)
$V_E = 2.7\ V - 0.7\ V$
$V_E = 2.0\ V$

$I_E = V_E/R_E$ (Eq. 8-3)
$I_E = 2.0\ V/1\ \Omega$
$I_E = 2\ mA$

$I_C \approx I_E$ (Eq. 8-4)

$V_C = V_{CC} - I_C R_C$ (Eq. 8-5)
$V_C = 15\ V - (2\ mA)(2.7\ \Omega)$
$V_C = 9.59\ V$

$V_{CE} = V_C - V_E$ (Eq. 8-6)
$V_{CE} = 9.59\ V - 2.0\ V$
$V_{CE} = 7.59\ V$

Answer: The Q point is $I_C = 2$ mA, and $V_{CE} = 7.59$ V.

8-9. *Given:*

$R_1 = 330\ k\Omega$
$R_2 = 100\ k\Omega$
$R_C = 150\ k\Omega$
$R_E = 51\ k\Omega$
$V_{CC} = 10\ V$
$V_{BE} = 0.7\ V$
$V_{BB} = 2.33\ V$ (from Prob. 8-3)
$V_E = 1.63\ V$ (from Prob. 8-3)
$I_E = I_C = 31.96\ \mu A$ (from Prob. 8-3)
$V_C = 5.21\ V$ (from Prob. 8-3)

Solution:

$V_{CE} = V_C - V_E$ (Eq. 8-6)
$V_{CE} = 5.21\ V - 1.63\ V$
$V_{CE} = 3.58\ V$

Answer: The Q point is $I_C = 31.96\ \mu A$, and $V_{CE} = 3.58$ V.

8-10. *Given:*

$R_1 = 150\ \Omega$
$R_2 = 33\ \Omega$
$R_C = 39\ \Omega$
$R_E = 10\ \Omega$
$V_{CC} = 12\ V$
$V_{BE} = 0.7\ V$

Solution:

$V_{BB} = [R_2/(R_1 + R_2)]V_{CC}$ (Eq. 8-1)
$V_{BB} = [33\ \Omega/(150\ \Omega + 33\ \Omega)]12\ V$
$V_{BB} = 2.16\ V$

$V_E = V_{BB} - V_{BE}$ (Eq. 8-2)
$V_E = 2.16\ V - 0.7\ V$
$V_E = 1.46\ V$

$I_E = V_E/R_E$ (Eq. 8-3)
$I_E = 1.46\ V/10\ \Omega$
$I_E = 146\ mA$

$I_C \approx I_E$ (Eq. 8-4)

$V_C = V_{CC} - I_C R_C$ (Eq. 8-5)
$V_C = 12\ V - (146\ mA)(39\ \Omega)$
$V_C = 6.3\ V$

$V_{CE} = V_C - V_E$ (Eq. 8-6)
$V_{CE} = 6.3\ V - 1.46\ V$
$V_{CE} = 4.85\ V$

Answer: The Q point is $I_C = 146$ mA, and $V_{CE} = 4.85$ V.

8-11. *Given:*

$R_1 = 330\ k\Omega \pm 5\%$
$R_2 = 100\ k\Omega \pm 5\%$
$R_C = 150\ k\Omega \pm 5\%$
$R_E = 51\ k\Omega \pm 5\%$
$V_{CC} = 10\ V$
$V_{BE} = 0.7\ V$

Solution:

$V_{BB(max)} = [R_{2(max)}/(R_{1(min)} + R_{2(max)})]V_{CC}$ (Eq. 8-1)
$V_{BB(max)} = [105\ k\Omega/(313.5\ k\Omega + 105\ k\Omega)]10\ V$
$V_{BB(max)} = 2.51\ V$

$V_{BB(min)} = [R_{2(min)}/(R_{1(max)} + R_{2(min)})]V_{CC}$ (Eq. 8-1)
$V_{BB(min)} = [95\ k\Omega/(346.5\ k\Omega + 95\ k\Omega)]10\ V$
$V_{BB(min)} = 2.15\ V$

$V_{E(max)} = V_{BB(max)} - V_{BE}$ (Eq. 8-2)
$V_{E(max)} = 2.51\ V - 0.7\ V$
$V_{E(max)} = 1.81\ V$

$V_{E(min)} = V_{BB(min)} - V_{BE}$ (Eq. 8-2)
$V_{E(min)} = 2.15\ V - 0.7\ V$
$V_{E(min)} = 1.45\ V$

$I_{E(max)} = V_{E(max)}/R_{E(min)}$ (Eq. 8-3)
$I_{E(max)} = 1.81\ V/48.45\ k\Omega$
$I_{E(max)} = 37.36\ \mu A$

$I_{E(min)} = V_{E(min)}/R_{E(max)}$ (Eq. 8-3)
$I_{E(min)} = 1.45\ V/53.55\ k\Omega$
$I_{E(min)} = 27.08\ \mu A$

$I_C \approx I_E$ (Eq. 8-4)

Answer: The lowest collector current is 27.08 μA, and the highest collector current is 37.36 μA.

8-12. *Given:*

$R_1 = 150\ \Omega$
$R_2 = 33\ \Omega$
$R_C = 39\ \Omega$
$R_E = 10\ \Omega$
$V_{CC} = 12\ V \pm 10\%$
$V_{BE} = 0.7\ V$

Solution:

$V_{BB(max)} = [R_2/(R_1 + R_2)]V_{CC(max)}$ (Eq. 8-1)
$V_{BB(max)} = [33\ \Omega/(150\ \Omega + 33\ \Omega)]13.2\ V$
$V_{BB(max)} = 2.38\ V$

$V_{E(max)} = V_{BB(max)} - V_{BE}$ (Eq. 8-2)
$V_{E(max)} = 2.38\ V - 0.7\ V$
$V_{E(max)} = 1.68\ V$

$I_{E(max)} = V_{E(max)}/R_E$ (Eq. 8-3)
$I_{E(max)} = 1.68\ V/10\ \Omega$
$I_{E(max)} = 168\ mA$

$V_{BB(min)} = [R_2/(R_1 + R_2)]V_{CC(min)}$ (Eq. 8-1)
$V_{BB(min)} = [33\ \Omega/(150\ \Omega + 33\ \Omega)]10.8\ V$
$V_{BB(min)} = 1.95\ V$

$V_{E(\min)} = V_{BB(\min)} - V_{BE}$ (Eq. 8-2)
$V_{E(\min)} = 1.95\text{ V} - 0.7\text{ V}$
$V_{E(\min)} = 1.25\text{ V}$

$I_{E(\min)} = V_{E(\min)}/R_E$ (Eq. 8-3)
$I_{E(\min)} = 1.25\text{ V}/10\ \Omega$
$I_{E(\min)} = 125\text{ mA}$

Answer: The lowest collector current 125 mA, and the highest collector current is 168 mA.

8-13. *Given:*

$R_B = 10\text{ k}\Omega$
$R_C = 4.7\text{ k}\Omega$
$R_E = 10\text{ k}\Omega$
$V_{CC} = 12\text{ V}$
$V_{EE} = -12\text{ V}$

Solution:

$I_E = (-0.7\text{ V} - V_{EE})/R_E$
$I_E = [-0.7\text{ V} - (-12\text{ V})]/10\text{ k}\Omega$
$I_E = 1.13\text{ mA}$

$V_C = V_{CC} - I_C R_C$
$V_C = 12\text{ V} - (1.13\text{ mA})(4.7\text{ k}\Omega)$
$V_C = 6.69\text{ V}$

Answer: The emitter current is 1.13 mA, and the collector voltage is 6.69 V.

8-14. *Given:*

$R_B = 20\text{ k}\Omega$
$R_C = 9.4\text{ k}\Omega$
$R_E = 20\text{ k}\Omega$
$V_{CC} = 12\text{ V}$
$V_{EE} = -12\text{ V}$

Solution:

$I_E = (-0.7\text{ V} - V_{EE})R_E$
$I_E = [-0.7\text{ V} -(-12\text{ V})]/20\text{ k}\Omega$
$I_E = 565\ \mu\text{A}$

$V_C = V_{CC} - I_C R_C$
$V_C = 12\text{ V} - (565\ \mu\text{A})(9.4\text{ k}\Omega)$
$V_C = 6.69\text{ V}$

Answer: The emitter current is 565 μA, and the collector voltage is 6.69 V.

8-15. *Given:*

$R_B = 10\text{ k}\Omega \pm 5\%$
$R_C = 4.7\text{ k}\Omega \pm 5\%$
$R_E = 10\text{ k}\Omega \pm 5\%$
$V_{CC} = 12\text{ V}$
$V_{EE} = -12\text{ V}$

Solution:

$I_{E(\max)} = (-0.7\text{ V} - V_{EE})/R_{E(\min)}$ (Eq. 8-14)
$I_{E(\max)} = [-0.7\text{ V} - (-12\text{ V})]/9.5\text{ k}\Omega$
$I_{E(\max)} = 1.19\text{ mA}$

$V_{C(\max)} = V_{CC} - I_{C(\min)}R_{C(\min)}$ (Eq. 8-15)
$V_{C(\max)} = 12\text{ V} - (1.08\text{ mA})(4465\text{ k}\Omega)$
$V_{C(\max)} = 7.18\text{ V}$

$I_{E(\min)} = (-0.7\text{ V} - V_{EE})/R_{E(\max)}$ (Eq. 8-14)
$I_{E(\min)} = [-0.7\text{ V} - (-12\text{ V})]/10.5\text{ k}\Omega$
$I_{E(\min)} = 1.08\text{ mA}$

$V_{C(\min)} = V_{CC} - I_{C(\max)}R_{C(\max)}$ (Eq. 8-15)
$V_{C(\min)} = 12\text{ V} - (1.19\text{ mA})(4935\text{ k}\Omega)$
$V_{C(\min)} = 6.13\text{ V}$

Answer: The maximum collector voltage is 7.18 V. The minimum collector voltage is 6.13 V.

8-16. **a.** Increase: If R_1 increases, V_B decreases, V_E decreases, I_E decreases, I_C decreases, the voltage drop across R_C decreases, and V_C increases.
b. Increase: If R_2 decreases, V_B decreases, V_E decreases, I_E decreases, I_C decreases, the voltage drop across R_C decreases, and V_C increases.
c. Increase: R_E increases, I_E decreases, I_C decreases, the voltage drop across R_C decreases, and V_C increases.
d. Increases: R_C decreases, the voltage drop across R_C decreases, and V_C increases.
e. Increases: If V_{CC} increases and the voltage drop across R_C does not change, V_C increases.
f. Remain the same: β_{dc} does not affect I_C. Therefore the voltage drop across R_C does not change, nor does V_C.

8-17. **a.** Decreases: If R_1 increases, V_B increases, V_E increases, I_E decreases, I_C decreases, the voltage drop across the collector resistor decreases, and V_C decreases.
b. Increases: If R_2 increases, V_B decreases, V_E decreases, I_E increases, I_C increases, the voltage drop across the collector resistor increases, and V_C increases.
c. Decreases: R_E increases, I_E decreases, I_C decreases, the voltage drop across the collector resistor decreases, and V_C decreases.
d. Increase: I_C remains the same, R_C increases, the voltage drop across the collector resistor increases, and V_C increases.
e. Increase: Since V_{BE} does not increase in proportion to the increase in voltage supply, as do V_B and V_{CC}, the voltage drop across the emitter resistor increases, causing I_E to increase. This causes the voltage drop across the collector resistor to increase and V_C to increase.
f. Remain the same: β_{dc} does not affect I_C. Therefore the voltage drop across R_C does not change, nor does V_C.

8-18. **a.** The approximate collector voltage is 12 V when R_1 is open due to no collector current.
b. The approximate collector voltage is 2.93 V when R_2 is open, the transistor is in saturation. CEB can be approximated as a short.
c. The approximate collector voltage is 12 V when R_E is open due to no collector current.
d. The approximate collector voltage is 0.39 V when R_C is open. The collector current is zero, therefore the base current is equal to the emitter current. The circuit becomes a voltage divider of 150 Ω and 33 Ω driving 10 Ω through the base-emitter diode. Thevenize the base voltage divider to get a V_{TH} = 2.16 V and a R_{TH} = 27 V Ω. This Thevenin circuit has a load of 10 Ω and a diode. Now solve for a current of 39.57 mA, which leads to an emitter voltage of 395 mV.
e. The approximate collector voltage is 12 V when the collector-emitter is open due to no collector current.

8-19. **a.** If R_1 is open, the base voltage increases to 10 V and the transistor cuts off. Therefore, the collector voltage is zero.
b. If R_2 is open, the transistor goes into saturation, similar to the preceding problem. Again, you can approximate the saturated transistor as a CEB short; that is, all three terminals shorted. Then, 10 kΩ is in parallel with 3.6 kΩ, which is 2.65 kΩ. This is in series with 1 kΩ and 10 V. The series current is 10 V divided by 3.65 kΩ, or 2.74 mA. Multiply by 2.65 kΩ to get 7.57 V, the approximate value of collector voltage.
c. With R_E open, there is no collector current and the collector voltage is zero.
d. With R_C open, the transistor has no collector current. Similar to the preceding problem, the circuit becomes a voltage divider driving the emitter resistor through

the base-emitter diode. The Thevenin voltage and resistance facing the base-emitter diode are 1.8 V and 1.8 kΩ. The current through the emitter resistor is (1.8 V – 0.7 V) divided by (1.8 kΩ + 1 kΩ), or 0.393 mA. Multiply by 1 kΩ to get 0.393 V for the voltage across the emitter resistor. Subtract this from 10 V to gel 9.6 V at the emitter node. Subtract 0.7 V to get 8.9 V at the base node. Add 0.7 V to get the voltage at the collector node. The final answer is therefore 9.4 V at the collector when R_C is open. If you don't believe it, build the circuit and measure the collector voltage with the collector resistor open.

e. When the collector-emitter terminals are open, there is no collector current and the collector voltage is zero.

8-20. *Given:*

$R_1 = 10$ kΩ
$R_2 = 2.2$ kΩ
$R_E = 1$ kΩ
$R_C = 3.6$ kΩ
$V_{CC} = 10$ V
$V_{BE} = 0.7$ V

Solution:

$V_2 = [R_2/(R_1 + R_2)]V_{CC}$
$V_2 = [2.2$ kΩ$/(10$ kΩ $+ 2.2$ kΩ$)]10$ V
$V_2 = 1.8$ V

$V_{RE} = V_2 - 0.7$ V
$V_{RE} = 1.8$ V $- 0.7$ V
$V_{RE} = 1.1$ V

$I_E = V_{RE}/R_E$
$I_E = 1.1$ V/1 kΩ
$I_E = 1.1$ mA

$I_C \approx I_E$ (Eq. 8-4)

$V_C = I_C R_C$
$V_C = (1.1$ mA$)(3.6$ kΩ$)$
$V_C = 3.96$ V

Answer: The collector voltage is 3.96 V.

8-21. *Given:*

$R_1 = 10$ kΩ
$R_2 = 2.2$ kΩ
$R_E = 1$ kΩ
$R_C = 3.6$ kΩ
$V_{CC} = 10$ V
$V_{BE} = 0.7$ V
$V_2 = 1.8$ V (from Prob. 8-20)
$V_{RE} = 1.1$ V (from Prob. 8-20)
$I_E = 1.1$ mA (from Prob. 8-20)
$V_C = 3.96$ V (from Prob. 8-20)

Solution:

$V_{CE} = V_{CC} - V_C - V_{RE}$
$V_{CE} = 10$ V $- 3.96$ V $- 1.1$ V
$V_{CE} = 4.94$ V

Answer: The collector-emitter voltage is –4.94 V since the collector is less positive than the emitter.

8-22. *Given:*

$R_1 = 10$ kΩ
$R_2 = 2.2$ kΩ
$R_E = 1$ kΩ
$R_C = 3.6$ kΩ
$V_{CC} = 10$ V
$V_{BE} = 0.7$ V
$V_2 = 1.8$ V (from Prob. 8-20)
$V_{RE} = 1.1$ V (from Prob. 8-20)
$I_E = 1.1$ mA (from Prob. 8-20)
$V_C = 3.96$ V (from Prob. 8-20)

Solution: Because of the voltage divider, there will always be a 1.1-V drop across R_E, and at saturation $V_{CE} = 0$ V. This leaves 8.9 V across R_C at saturation.

$I_C = 8.9$ V/R_c
$I_C = 8.9$ V/3.6 kΩ
$I_C = 2.47$ mA

At cutoff, the maximum possible voltage across V_{CE} is 8.9 V.

Answer: The saturation current is 2.47 mA, and the collector-emitter cutoff voltage is 8.9 V.

8-23. *Given:*

$R_1 = 10$ kΩ
$R_2 = 2.2$ kΩ
$R_E = 1$ kΩ
$R_C = 3.6$ kΩ
$V_{CC} = -10$ V
$V_{BE} = 0.7$ V

Solution:

$V_{BB} = [R_2/(R_1 + R_2)]V_{CC}$
$V_{BB} = [2.2$ kΩ$/(10$ kΩ $+ 2.2$ kΩ$)] - 10$ V
$V_{BB} = -1.8$ V

$V_E = V_2 + 0.7$ V
$V_E = -1.8$ V $+ 0.7$ V
$V_E = -1.1$ V

$I_E = V_E/R_E$
$I_E = 1.1$ V/1 kΩ
$I_E = 1.1$ mA

$I_C \approx I_E$ (Eq. 8-4)

$V_C = V_{CC} + I_C R_C$
$V_C = -10$ V $+ (1.1$ mA$)(3.6$ kΩ$)$
$V_C = -6.04$ V

Answer: The collector voltage is –6.04 V, and the emitter voltage is –1.1 V.

CRITICAL THINKING

8-24. The circuit is no longer considered stiff or independent of Beta. The base current is not small as compared to the voltage divider current.

8-25. The maximum power dissipation of the 2N3904 is 625 mW. The transistor is dissipating 705 mW. The transistor will probably overheat and fail.

8-26. As long as the voltmeter has a high enough input resistance, it should read approximately 4.83 V.

8-27. Increase the power supply value, short R_1.

8-28. Connect an ammeter between the power supply and the circuit. Measure V_{R1} and V_C, then calculate and add their respective currents.

8-29. *Given:* (*for Q_1*):

$R_1 = 1.8$ kΩ
$R_2 = 300$ Ω
$R_E = 240$ Ω
$R_C = 1$ kΩ
$V_{CC} = 15$ V
$V_{BE} = 0.7$ V

Solution:

$V_{BB} = [R_2/(R_1 + R_2)]V_{CC}$ (Eq. 8-1)
$V_{BB} = [300\ \Omega/(1.8\ \text{k}\Omega + 300\ \Omega)]15\ \text{V}$
$V_{BB} = 2.14\ \text{V}$

$V_E = V_{BB} - 0.7\ \text{V}$ (Eq. 8-2)
$V_E = 2.14\ \text{V} - 0.7\ \text{V}$
$V_E = 1.44\ \text{V}$

$I_E = V_E/R_E$ (Eq. 8-3)
$I_E = 1.44\ \text{V}/240\ \Omega$
$I_E = 6\ \text{mA}$

$I_C \approx I_E$ (Eq. 8-4)

$V_C = V_{CC} - I_C R_C$ (Eq. 8-5)
$V_C = 15\ \text{V} - (6\ \text{mA})(1\ \text{k}\Omega)$
$V_C = 9.0\ \text{V}$

Given (for Q_2):

$R_1 = 910\ \Omega$
$R_2 = 150\ \Omega$
$R_E = 120\ \Omega$
$R_C = 510\ \Omega$
$V_{CC} = 15\ \text{V}$
$V_{BE} = 0.7\ \text{V}$

Solution:

$V_{BB} = [R_2/(R_1 + R_2)]V_{CC}$ (Eq. 8-1)
$V_{BB} = [150\ \Omega/(910\ \Omega + 150\ \Omega)]15\ \text{V}$
$V_{BB} = 2.12\ \text{V}$

$V_E = V_{BB} - 0.7\ \text{V}$ (Eq. 8-2)
$V_E = 2.12\ \text{V} - 0.7\ \text{V}$
$V_E = 1.42\ \text{V}$

$I_E = V_E/R_E$ (Eq. 8-3)
$I_E = 1.42\ \text{V}/120\ \Omega$
$I_E = 11.83\ \text{mA}$

$I_C \approx I_E$ (Eq. 8-4)

$V_C = V_{CC} - I_C R_C$ (Eq. 8-5)
$V_C = 15\ \text{V} - (11.83\ \text{mA})(510\ \Omega)$
$V_C = 8.97\ \text{V}$

Given (for Q_3):

$R_1 = 1\ \text{k}\Omega$
$R_2 = 180\ \Omega$
$R_E = 150\ \Omega$
$R_C = 620\ \Omega$
$V_{CC} = 15\ \text{V}$
$V_{BE} = 0.7\ \text{V}$

Solution:

$V_{BB} = [R_2/(R_1 + R_2)]V_{CC}$ (Eq. 8-1)
$V_{BB} = [180\ \Omega/(1\ \text{k}\Omega + 180\ \Omega)]15\ \text{V}$
$V_{BB} = 2.29\ \text{V}$

$V_E = V_{BB} - 0.7\ \text{V}$ (Eq. 8-2)
$V_E = 2.29\ \text{V} - 0.7\ \text{V}$
$V_E = 1.59\ \text{V}$

$I_E = V_E/R_E$ (Eq. 8-3)
$I_E = 1.59\ \text{V}/150\ \Omega$
$I_E = 10.6\ \text{mA}$

$I_C \approx I_E$ (Eq. 8-4)

$V_C = V_{CC} - I_C R_C$ (Eq. 8-5)
$V_C = 15\ \text{V} - (10.6\ \text{mA})(620\ \Omega)$
$V_C = 8.43\ \text{V}$

Answer: The collector voltage for Q_1 is 9.0 V, for Q_2 is 8.97 V, and for Q_3 is 8.43 V.

8-30. *Given:*

$R_1 = 10\ \text{k}\Omega$
$R_E = 1\ \text{k}\Omega$
$R_C = 8.2\ \text{k}\Omega$
$V_{CC} = 20\ \text{V}$
$V_D = 0.7\ \text{V}$

Solution:

$V_{BB} = 3(V_D)$
$V_{BB} = 3(0.7\ \text{V})$
$V_{BB} = 2.1\ \text{V}$

$V_E = V_{BB} - 0.7\ \text{V}$ (Eq. 8-2)
$V_E = 2.1\ \text{V} - 0.7\ \text{V}$
$V_E = 1.4\ \text{V}$

$I_E = V_E/R_E$ (Eq. 8-3)
$I_E = 1.4\ \text{V}/1\ \text{k}\Omega$
$I_E = 1.4\ \text{mA}$

$I_C \approx I_E$ (Eq. 8-4)

$V_C = V_{CC} - I_C R_C$ (Eq. 8-5)
$V_C = 20\ \text{V} - (1.4\ \text{mA})(8.2\ \text{k}\Omega)$
$V_C = 8.52\ \text{V}$

Answer: The emitter current is 1.4 mA, and the collector voltage is 8.52 V.

8-31. *Given:*

$V_{BB(1)} = 2\ \text{V}$
$R_{E(1)} = 200\ \Omega$
$R_{C(1)} = 1\ \text{k}\Omega$
$R_{E(2)} = 1\ \text{k}\Omega$
$V_{CC} = 16\ \text{V}$

Solution:

$V_{E(1)} = V_{BB(1)} - 0.7\ \text{V}$ (Eq. 8-2)
$V_{E(1)} = 2.0\ \text{V} - 0.7\ \text{V}$
$V_{E(1)} = 1.3\ \text{V}$

$I_{E(1)} = V_E/R_E$ (Eq. 8-3)
$I_{E(1)} = 1.3\ \text{V}/200\ \Omega$
$I_{E(1)} = 6.5\ \text{mA}$

$I_C \approx I_E$ (Eq. 8-4)

$V_{C(1)} = V_{CC} - I_C R_C$ (Eq. 8-5)
$V_{C(1)} = 16\ \text{V} - (6.5\ \text{mA})(1\ \text{k}\Omega)$
$V_{C(1)} = 9.5\ \text{V}$

$V_{C(1)} = V_{BB(2)}$

$V_{E(2)} = V_{BB(2)} - 0.7\ \text{V}$ (Eq. 8-2)
$V_{E(2)} = 9.5\ \text{V} - 0.7\ \text{V}$
$V_{E(2)} = 8.8\ \text{V}$

Answer: The output voltage is 8.8 V.

8-32. *Given:*

$R_1 = 620\ \Omega$
$R_2 = 680\ \Omega$
$R_E = 200\ \Omega$
$V_{CC} = 12\ \text{V}$
$V_{BE} = 0.7\ \text{V}$

Solution:

$V_2 = [R_2/(R_1 + R_2)]V_{CC}$
$V_2 = [680\ \Omega/(620\ \Omega + 680\ \Omega)]12\ \text{V}$
$V_2 = 6.28\ \text{V}$

$V_{RE} = V_2 - 0.7\ \text{V}$
$V_{RE} = 6.28\ \text{V} - 0.7\ \text{V}$
$V_{RE} = 5.58\ \text{V}$

$I_E = V_{RE}/R_E$ (Eq. 8-3)
$I_E = 5.58\ \text{V}/200\ \Omega$

$I_E = 27.9$ mA

$I_{LED} \approx I_E$

Answer: The LED current is 27.9 mA.

8-33. *Given:*

$R_1 = 620\ \Omega$
$R_E = 200\ \Omega$
$V_{CC} = 12$ V
$V_{BE} = 0.7$ V
$V_Z = 6.2$ V

Solution:

$V_{RE} = V_Z - 0.7$ V
$V_{RE} = 6.2$ V $- 0.7$ V
$V_{RE} = 5.5$ V

$I_E = V_{RE}/R_E$ (Eq. 8-3)
$I_E = 5.5$ V$/200\ \Omega$
$I_E = 27.5$ mA

$I_{LED} \approx I_E$

Answer: The LED current is 27.5 mA.

8-34. *Given:*

$R_E = 51$ kΩ
$R_1 = 3.3R_2$; this ratio is necessary to prevent moving the Q point. Assume $\beta_{dc} = 100$

Solution:

$R_1 \| R_2 < 0.01\ \beta_{dc}R_E$ (Eq. 8-9)
$R_1 \| R_2 = 0.01(100)(51$ kΩ$)$
$R_1 \| R_2 = 51$ kΩ

Since R_2 is the smaller of the two resistors, make it 51 kΩ. Then the parallel resistance will not be higher than 51 kΩ, which satisfies the requirement.

$R_1 = 3.3R_2$
$R_1 = 3.3(51$ kΩ$)$
$R_1 = 168.3$ kΩ

Answer: R_1 maximum of 168.3 kΩ, R_2 maximum of 51 kΩ, and the ratio between them 3.3:1.

8-35. *Answer:* With V_B at 10 V and R_2 is good, the trouble is R_1 shorted.

8-36. *Answer:* Since V_B is 0.7 V and V_E is 0 V, the trouble is R_E is shorted.

8-37. *Answer:*

Trouble 3: Since V_C is 10 V and V_E is 1.1 V, the transistor is good. Therefore the trouble is R_C, which is shorted.

Trouble 4: Since all the voltages are the same, the trouble is that all the transistor terminals are shorted together.

8-38. *Answer:*

Trouble 5: Since V_B is 0 V, it is either R_1 open or R_2 shorted. R_2 is OK, so the trouble is R_1 open.

Trouble 6: R_2 is open.

8-39. *Answer:*

Trouble 7: Since V_C is 10 V, there is an open below it or a short above it. A shorted R_C would not affect V_B; therefore there must be an open below it. If the transistor is open, V_B would be 0 V; therefore the trouble is an open R_E.

Trouble 8: R_2 is shorted.

8-40. *Answer:*

Trouble 9: Since the base voltage is 1.1 V, it appears that the voltage divider is working but not properly. The emitter voltage is 0.7 V less than the base, so the emitter-base junction is working. If R_C is open, the meter would complete the circuit and give a low voltage reading. The trouble is an open R_C.

Trouble 10: This is very similar to trouble 9 except that the collector voltage is 10 V. Since source voltage is read above an open, the trouble is an open collector-base junction.

8-41. *Answer:*

Trouble 11: Since all the voltages are 0 V, the power supply is not working.

Trouble 12: With the emitter voltage at 0 V and the base voltage at 1.83 V, the emitter-base diode of the transistor is open.

Chapter 9 AC Models

SELF-TEST

1. a	**7. b**	**12. d**	**17. c**
2. b	**8. b**	**13. b**	**18. b**
3. c	**9. c**	**14. b**	**19. b**
4. c	**10. c**	**15. d**	**20. c**
5. a	**11. b**	**16. b**	**21. a**
6. d			

JOB INTERVIEW QUESTIONS

7. To permit the output voltage to swing over the largest possible voltage when the input signal is large enough to produce a maximum output.

8. Models provide mathematical and logical insight into the operation of a device. The two common transistor models are the T and the π.

11. It would become zero because there is no collector current.

PROBLEMS

9-1. *Given:*

$C = 47\ \mu$F
$R = 10$ kΩ

Solution:

$X_C = 1/(2\pi fC)$
$X_C < 0.1R$ (Eq. 9-1)
$1/(2\pi fC) = 0.1R$
$1/(2\pi C) = (0.1R)f$
$f = 1/\{[2\pi(47\mu\text{F})][0.1(10\text{ k}\Omega)]\}$
$f = 3.39$ Hz

Answer: The lowest frequency where good coupling exists is 3.39 Hz.

9-2. *Given:*

$C = 47\ \mu$F
$R = 1$ kΩ

Solution:

$X_C = 1/(2\pi fC)$
$X_C < 0.1R$ (Eq. 9-1)
$1/(2\pi fC) = 0.1R$
$1/(2\pi C) = (0.1R)f$
$f = 1/\{[2\pi(47\ \mu\text{F})][0.1(1\text{ k}\Omega)]\}$
$f = 33.9$ Hz

$V_E = V_{BB} - V_{BE}$
$V_E = 2.7\ \text{V} - 0.7\ \text{V}$
$V_E = 2.0\ \text{V}$

$I_E = V_E/R_E$ (Eq. 8-3)
$I_E = 2.0\ \text{V}/940\ \Omega$
$I_E = 2.128\ \text{mA}$

$i_{e(\text{pp})} < 0.1\ I_{EQ}$ (Eq. 9-6)
$i_{e(\text{pp})\max} = 0.1\ (2.13\ \text{mA})$
$i_{e(\text{pp})\max} = 213\ \mu\text{A}$

Answer: The maximum ac emitter current for small signal operation is 213 µA.

9-11. *Given:*

$i_c = 15\ \text{mA}$
$i_b = 100\ \mu\text{A}$

Solutions:

$\beta = i_c/i_b$ (Eq. 9-8)
$\beta = 15\ \text{mA}/100\ \mu\text{A}$
$\beta = 150$

Answer: The ac beta is 150.

9-12. *Given:*

$\beta = 200$
$i_b = 12.5\ \mu\text{A}$

Solutions:

$\beta = i_c/i_b$ (Eq. 9-8)
$i_c = \beta i_b$
$i_c = 200\ (12.5\ \mu\text{A})$
$i_c = 2.5\ \text{mA}$

Answer: The ac collector current is 2.5 mA.

9-13. *Given:*

$\beta = 100$
$i_c = 4\ \text{mA}$

Solutions:

$\beta = i_c/i_b$ (Eq. 9-8)
$i_b = i_b/\beta$
$i_b = 4\ \text{mA}/100$
$i_b = 40\ \mu\text{A}$

Answer: The ac base current is 40 µA.

9-14. *Given:*

$R_1 = 1.5\ \text{k}\Omega$
$R_2 = 330\ \Omega$
$R_C = 1.2\ \text{k}\Omega$
$R_E = 470\ \Omega$
$V_{CC} = 15\ \text{V}$
$V_{BE} = 0.7\ \text{V}$

Solution:

$V_{BB} = [R_2/(R_1 + R_2)]V_{CC}$ (Voltage divider formula)
$V_{BB} = [330\ \Omega/(1.5\ \text{k}\Omega + 330\ \Omega)]15\ \text{V}$
$V_{BB} = 2.7\ \text{V}$

$V_E = V_{BB} - V_{BE}$
$V_E = 2.7\ \text{V} - 0.7\ \text{V}$
$V_E = 2.0\ \text{V}$

$I_E = V_E/R_E$ (Eq. 8-3)
$I_E = 2.0\ \text{V}/470\ \Omega$
$I_E = 4.26\ \text{mA}$

$r'_e = 25\ \text{mV}/I_E$ (Eq. 9-10)
$r'_e = 226.7\ \Omega\ \text{mV}/4.26\ \text{mA}$
$r'_e = 5.88\ \Omega$

Answer: The ac resistance of the emitter diode is 5.88 Ω.

9-15. *Given:*

$I_E = 2.13\ \text{mA}$ (from Prob. 9-10)

Solution:

$r'_e = 25\ \text{mV}/I_E$ (Eq. 9-10)
$r'_e = 25\ \text{mV}/2.13\ \text{mA}$
$r'_e = 11.7\ \Omega$

Answer: The ac resistance of the emitter diode is 11.7 Ω.

9-16. *Given:*

$r'_e = 5.88\ \Omega$ (from Prob. 9-14)
$\beta = 200$

Solution:

$Z_{\text{in(base)}} = \beta r'_e$ (Eq. 9-11)
$Z_{\text{in(base)}} = 200\ (5.88\ \Omega)$
$Z_{\text{in(base)}} = 1.18\ \text{k}\Omega$

Answer: The input impedance to the base is 1.18 kΩ.

9-17. *Given:*

$r'_e = 11.7\ \Omega$ (from Prob. 9-15)
$\beta = 200$

Solution:

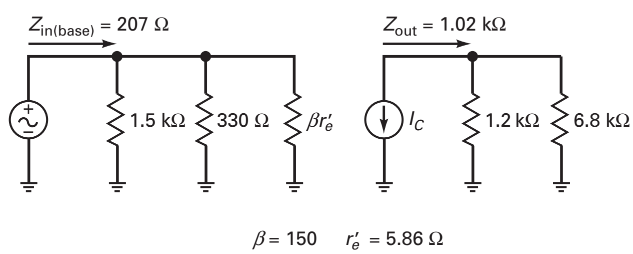
$Z_{\text{in(base)}} = \beta r'_e$ (Eq. 9-11)
$Z_{\text{in(base)}} = 200\ (11.7\ \Omega)$
$Z_{\text{in(base)}} = 2.34\ \text{k}\Omega$

Answer: The input impedance to the base is 2.34 kΩ.

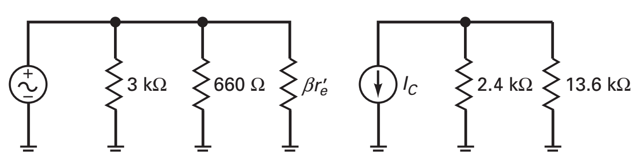
9-18. *Given:* Since the collector resistor does not affect the dc emitter current, the ac emitter resistance does not change. Since the beta did not change either, the input resistance remains the same as in problem 9-16.

Answer: The input impedance to the base is 1.18 kΩ.

9-19. *Answer:*



9-20. *Answer:*



9-21. *Answer:*

min $h_{fe} = 50$
max $h_{fe} = 200$
Current is 1 mA
Temperature 25°C

9-22. *Given:*

$I_E = I_C = 5\ \text{mA}$
From Fig. 13 on the data sheet h_{ie} is 875 Ω at 5 mA; from Fig. 11 on the data sheet h_{fe} is 150 Ω at 5 mA.

Solution:

$r'_e = (25\ \text{mV})/I_E$ (Eq. 9-10)
$r'_e = (25\ \text{mV})/5\ \text{mA}$
$r'_e = 5\ \Omega$

$r'_e = h_{ic}/h_{fe}$
$r'_e = 875\ \Omega/150$
$r'_e = 5.83$

Answer: The value of r'_e is 5.83 Ω. The calculated value is larger than the ideal.

CRITICAL THINKING

9-23. *Answer:* The capacitor has a certain amount of leakage current, and this current will flow through the resistor and create a voltage drop across the resistor.

9-24. *Answer:* A wire has a very small inductance value. As the frequency increases, the inductive reactance starts to become significant. The wires connected to the capacitor and the leads will start to have an inductive reactance, causing the voltage to rise at the node.

9-25. *Given:*

$R_1 = 10\ k\Omega$
$R_2 = 30\ k\Omega$
$R_3 = 20\ k\Omega$
$R_4 = 40\ k\Omega$
$R_5 = 40\ k\Omega$
$C = 10\ \mu F$

Solution:

$R_{12(EQ)} = 1/(1/R_1 + 1/R_2)$
$R_{12(EQ)} = 1/(1/(10\ k\Omega) + 1/(30\ k\Omega))$
$R_{12(EQ)} = 7.5\ k\Omega$

$R_{35(EQ)} = 1/(1/R_3 + 1/R_4 + 1/R_5)$
$R_{35(EQ)} = 1/[1/(20\ k\Omega) + 1/(40\ k\Omega) + 1/(40\ k\Omega)]$
$R_{35(EQ)} = 10\ k\Omega$

$R_T = R_{12(EQ)} + R_{35(EQ)}$
$R_T = 7.5\ k\Omega + 10\ k\Omega$
$R_T = 17.5\ k\Omega$

$X_C = 1/(2\pi fC)$
$X_C < 0.1R$ (Eq. 9-1)
$1/(2\pi fC) = 0.1R$
$1/(2\pi C) = (0.1R)(f)$
$1/(2\pi C)(0.1R) = f$
$f = 1/\{[2\pi(10\ \mu F)][0.1(17.5\ k\Omega)]\}$
$f = 9.09\ Hz$

Answer: The lowest frequency at which good coupling exists is 9.09 Hz.

9-26. *Given:*

$R_1 = 1\ k\Omega$
$R_2 = 4\ k\Omega$
$C = 2\ \mu F$

Answer: The Thevenin resistance is R_1 in parallel with R_2.

$R_{12(EQ)} = 1/(1/R_1 + 1/R_2)$
$R_{12(EQ)} = 1/[1/(1\ k\Omega) + 1/(4\ k\Omega)]$
$R_{12(EQ)} = 800\ \Omega$

$X_C = 1/(2\pi fC)$
$X_C < 0.1R$ (Eq. 9-5)
$1/(2\pi fC) = 0.1R$
$1/(2\pi C) = (0.1R)(f)$
$1/[(2\pi C)(0.1R) = f$
$f = 1/\{[2\pi(2\ \mu F)][0.1(800\ \Omega)]\}$
$f = 995\ Hz$

Answer: The lowest frequency at which good bypassing exists is 995 Hz.

9-27. *Given (for the first transistor):*

$R_1 = 10\ k\Omega$
$R_2 = 2.2\ k\Omega$
$R_C = 3.6\ k\Omega$
$R_E = 1\ k\Omega$
$V_{CC} = 10\ V$
$V_{BE} = 0.7\ V$
$\beta = 250$

Solution (for the first transistor):

$V_{BB} = [R_2/(R_1 + R_2)]V_{CC}$ (Eq. 8-1)
$V_{BB} = [2.2\ k\Omega/(10\ k\Omega + 2.2\ k\Omega)]10\ V$
$V_{BB} = 1.8\ V$

$V_E = V_{BB} - V_{BE}$ (Eq. 8-2)
$V_E = 1.8\ V - 0.7\ V$
$V_E = 1.1\ V$

$I_E = V_E/R_E$ (Eq. 8-3)
$I_E = 1.1\ V/1\ k\Omega$
$I_E = 1.1\ mA$

$r'_e = (25\ mV)/I_E$ (Eq. 9-10)
$r'_e = (25\ mV)/1.1\ mA$
$r'_e = 22.7\ \Omega$

$z_{in(base)} = \beta r'_e$ (Eq. 9-11)
$z_{in(base)} = (250)(22.7\ \Omega)$
$z_{in(base)} = 5.68\ k\Omega$

Answer (for the first transistor): The input impedance of the base is 5.68 kΩ.

Given (for the second transistor):

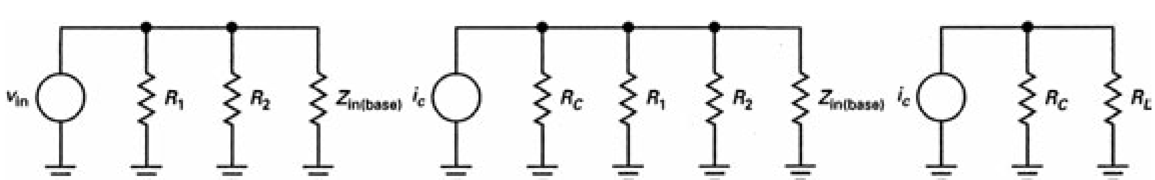
$R_1 = 10\ k\Omega$
$R_2 = 2.2\ k\Omega$
$R_C = 3.6\ k\Omega$
$R_E = 1\ k\Omega$
$V_{CC} = 10\ V$
$V_{BE} = 0.7\ V$
$\beta = 100$
$V_{BB} = 1.8\ V$ (from the first part of the problem)
$V_E = 1.1\ V$ (from the first part of the problem)
$I_E = 1.1\ mA$ (from the first part of the problem)
$r'_e = 22.7\ \Omega$ (from the first part of the problem)

Solution (for the second transistor):

$z_{in(base)} = \beta r'_e$ (Eq. 9-11)
$z_{in(base)} = (100)(22.7\ \Omega)$
$z_{in(base)} = 2.27\ k\Omega$

Answer: The input impedance of the first base is 5.68 kΩ, and the input impedance of the second base is 2.27 kΩ.

9-28. *Answer:* See figure at foot of page.



AC equivalent circuit for Prob. 9-26.

9-29. *Given:*

$R = 30\ \Omega$
$f = 20$ Hz to 20 kHz

Solution:

$X_C = 1/(2\pi fC)$
$X_C < 0.1R$ (Eq. 9-5)
$1/(2\pi fC) = 0.1R$
$1/(2\pi f) = (0.1R)(C)$
$1/(2\pi f)(0.1R) = C$
$C = 1/\{[2\pi(20\text{ Hz})][0.1(30\ \Omega)]\}$
$C = 2653\ \mu\text{F}$

Answer: The capacitor would have to be at least 2653 μF, or 2700 μF (standard value).

Chapter 10 Voltage Amplifiers

SELF-TEST

1. c	**8. b**	**15. a**	**22. c**
2. b	**9. c**	**16. a**	**23. b**
3. a	**10. c**	**17. d**	**24. a**
4. c	**11. d**	**18. b**	**25. a**
5. d	**12. b**	**19. a**	**26. a**
6. c	**13. a**	**20. d**	**27. b**
7. c	**14. d**	**21. b**	**28. c**

JOB INTERVIEW QUESTIONS

5. Coupling capacitors C_1 and C_2 must be replaced by wires. The ground reference has to be shifted to provide 0 V at the collector. Also, the bypass capacitor needs to be eliminated, and some of the resistors resized.
7. Very high input impedance to limit the current drawn from the preceding stage and to prevent distortion. Also, high current gain and low output impedance to provide a match to a speaker.
9. 100 is good choice for small-signal transistors.

PROBLEMS

10-1. *Given:*

$R_1 = 10\text{ k}\Omega$
$R_2 = 2.2\text{ k}\Omega$
$R_C = 3.6\text{ k}\Omega$
$R_E = 1\text{ k}\Omega$
$R_L = 10\text{ k}\Omega$
$V_{CC} = 10$ V
$V_{BE} = 0.7$ V

Solution:

$V_{BB} = [R_2/(R_1 + R_2)]V_{CC}$ (Eq. 8-1)
$V_{BB} = [2.2\text{ k}\Omega/(10\text{ k}\Omega + 2.2\text{ k}\Omega)]10\text{ V}$
$V_{BB} = 1.8$ V

$V_E = V_{BB} - V_{BE}$ (Eq. 8-2)
$V_E = 1.8\text{ V} - 0.7\text{ V}$
$V_E = 1.1$ V

$I_E = V_E/R_E$ (Eq. 8-3)
$I_E = 1.1\text{ V}/1\text{ k}\Omega$
$I_E = 1.1$ mA

$r'_e = (25\text{ mV})/I_E$ (Eq. 9-10)
$r'_e = (25\text{ mV})/1.1\text{ mA}$
$r'_e = 22.7\ \Omega$

$r_c = R_C \| R_L$ (Eq. 10-2)
$r_c = 3.6\text{ k}\Omega \| 10\text{ k}\Omega$
$r_c = 2.65\text{ k}\Omega$

$A_v = r_c / r'_e$ (Eq. 10-3)
$A_v = 2.65\text{ k}\Omega/22.7\ \Omega$
$A_v = 117$

$v_{out} = A_{vin}$
$v_{out} = 117(2\text{ mV})$
$v_{out} = 234$ mV

Answer: The output voltage is 234 mV.

10-2. *Given:*

$R_1 = 10\text{ k}\Omega$
$R_2 = 2.2\text{ k}\Omega$
$R_C = 3.6\text{ k}\Omega$
$R_E = 1\text{ k}\Omega$
$R_L = 5\text{ k}\Omega$
$V_{CC} = 10$ V
$V_{BB} = 1.8$ V (from Prob. 10-1)
$V_E = 1.1$ V (from Prob. 10-1)
$I_E = 1.1$ V (from Prob. 10-1)
$r'_e = 22.7\ \Omega$ (from Prob. 10-1)

Solution:

$r_c = R_C \| R_L$
$r_c = 3.6\text{ k}\Omega \| 5\text{ k}\Omega$
$r_c = 2093\text{ k}\Omega$

$A_v = r_c / r'_e$
$A_v = 2093\text{ k}\Omega/22.7\ \Omega$
$A_v = 92.2$

Answer: The voltage gain is 92.2.

10-3. *Given:*

$R_1 = 10\text{ k}\Omega$
$R_2 = 2.2\text{ k}\Omega$
$R_C = 3.6\text{ k}\Omega$
$R_E = 1\text{ k}\Omega$
$R_L = 10$ V
$V_{CC} = 15$ V

Solution:

$V_{BB} = [R_2/(R_1 + R_2)]V_{CC}$
$V_{BB} = [2.2\text{ k}\Omega/(10\text{ k}\Omega + 2.2\text{ k}\Omega)]15\text{ V}$
$V_{BB} = 2.7$ V

$V_E = V_{BB} - V_{BE}$
$V_E = 2.7\text{ V} - 0.7\text{ V}$
$V_E = 2.0$ V

$I_E = V_E/R_E$
$I_E = 2.0\text{ V}/1\text{ k}\Omega$
$I_E = 2$ mA

$r'_e = (25\text{ mV})/I_E$
$r'_e = (25\text{ mV})/2\text{ mA}$
$r'_e = 12.5\ \Omega$

$r_c = R_C \| R_L$
$r_c = 3.6\text{ k}\Omega \| 10\text{ k}\Omega$
$r_c = 2.65\text{ k}\Omega$

$A_v = r_c / r'_e$
$A_v = 2.65\text{ k}\Omega/12.5\ \Omega$
$A_v = 212$

$v_{out} = A_v(v_{in})$
$v_{out} = 212(1\text{ mV})$
$v_{out} = 212$ mV

Answer: The voltage gain is 212, the output voltage is 212 mV.

10-4. *Given:*

$R_1 = 10\ \text{k}\Omega$
$R_2 = 2.2\ \text{k}\Omega$
$R_C = 3.6\ \text{k}\Omega$
$R_E = 1\ \text{k}\Omega$
$R_L = 10\ \text{k}\Omega$
$R_G = 600\ \Omega$
$V_{BE} = 0.7\ \text{V}$
$V_{CC} = 15\ \text{V}$
Assume $\beta = 100$

Solution:

$V_{BB} = [R_2/(R_1 + R_2)]V_{CC}$
$V_{BB} = [2.2\ \text{k}\Omega/(10\ \text{k}\Omega + 2.2\ \text{k}\Omega)]15\ \text{V}$
$V_{BB} = 2.7\ \text{V}$

$V_E = V_{BB} - V_{BE}$
$V_E = 2.7\ \text{V} - 0.7\ \text{V}$
$V_E = 2.0\ \text{V}$

$I_E = V_E/R_E$
$I_E = 2.0\ \text{V}/1\ \text{k}\Omega$
$I_E = 2\ \text{mA}$

$r_e' = (25\ \text{mV})/I_E$
$r_e' = (25\ \text{mV})/2\ \text{mA}$
$r_e' = 12.5\ \Omega$

$r_c = R_C \| R_L$
$r_c = 3.6\ \text{k}\Omega \| 10\ \text{k}\Omega$
$r_c = 2.65\ \text{k}\Omega$

$A_\text{v} = r_c / r_e'$
$A_\text{v} = 2.65\ \text{k}\Omega/12.5\ \Omega$
$A_\text{v} = 212$

$z_\text{in} = R_1 \| R_2 \| \beta r_e'$
$z_\text{in} = 10\ \text{k}\Omega \| 2.2\ \text{k}\Omega \| 1.25\ \text{k}\Omega$
$z_\text{in} = 738\ \Omega$

$v_\text{in} = [z_\text{in}/(R_G + z_\text{in})]v_g$
$v_\text{in} = [738\ \Omega/(600\ \Omega + 738\ \Omega)]1\ \text{mV}$
$v_\text{in} = 551.57\ \mu\text{V}$

$v_\text{out} = A_\text{v}(v_\text{in})$
$v_\text{out} = 212(551.57\ \mu\text{V})$
$v_\text{out} = 117\ \text{mV}$

Answer: The voltage gain is 212, the output voltage is 117 mV.

10-5. *Given:*

$R_1 = 10\ \text{k}\Omega$
$R_2 = 2.2\ \text{k}\Omega$
$R_C = 3.6\ \text{k}\Omega$
$R_E = 2\ \text{k}\Omega$
$R_L = 10\ \text{k}\Omega$
$R_G = 600\ \Omega$
$V_{CC} = 10\ \text{V}$
$V_{BE} = 0.7\ \text{V}$
Assume $\beta = 100$

Solution:

$V_{BB} = [R_1/(R_1 + R_2)]V_{CC}$ (Eq. 8-1)
$V_{BB} = [10\ \text{k}\Omega/(10\ \text{k}\Omega + 2.2\ \text{k}\Omega)]10\ \text{V}$
$V_{BB} = 1.8\ \text{V}$

$V_E = V_{BB} - V_{BE}$ (Eq. 8-2)
$V_E = 1.8\ \text{V} - 0.7\ \text{V}$
$V_E = 1.1\ \text{V}$

$I_E = V_E/R_E$ (Eq. 8-3)
$I_E = 1.1\ \text{V}/2\ \text{k}\Omega$
$I_E = 0.55\ \text{mA}$

$r_e' = (25\ \text{mV})/I_E$ (Eq. 9-10)
$r_e' = (25\ \text{mV})/0.55\ \text{mA}$
$r_e' = 45.5\ \Omega$

$r_c = R_C \| R_L$ (Eq. 10-2)
$r_c = 3.6\ \text{k}\Omega \| 10\ \text{k}\Omega$
$r_c = 2.65\ \text{k}\Omega$

$A_\text{v} = r_c / r_e'$ (Eq. 10-3)
$A_\text{v} = 2.65\ \text{k}\Omega/45.5\ \Omega$
$A_\text{v} = 58$

$z_\text{in} = R_1 \| R_2 \| \beta r_e'$
$z_\text{in} = 10\ \text{k}\Omega \| 2.2\ \text{k}\Omega \| 100(45.5\ \Omega)$
$z_\text{in} = 1.29\ \text{k}\Omega$

$v_\text{in} = [z_\text{in}(R_G + z_\text{in})]v_g$ (Eq. 10-4)
$v_\text{in} = [1.29\ \text{k}\Omega/(600\ \Omega + 1.29\ \text{k}\Omega)]1\ \text{mV}$
$v_\text{in} = 0.683\ \text{mV}$

$v_\text{out} = A_\text{v}(v_\text{in})$
$v_\text{out} = 58(0.683\ \text{mV})$
$v_\text{out} = 39.6\ \text{mV}$

Answer: The output voltage is 39.6 mV.

10-6. *Given:*

$R_1 = 10\ \text{k}\Omega$
$R_2 = 2.2\ \text{k}\Omega$
$R_C = 3.6\ \text{k}\Omega$
$R_E = 1\ \text{k}\Omega$
$R_L = 10\ \text{k}\Omega$
$R_G = 300\ \Omega$
$V_{BE} = 0.7\ \text{V}$
$V_{CC} = 10\ \text{V}$
Assume $\beta = 100$

Solution:

$V_{BB} = [R_2/(R_1 + R_2)]V_{CC}$
$V_{BB} = [2.2\ \text{k}\Omega/(10\ \text{k}\Omega + 2.2\ \text{k}\Omega)]10\ \text{V}$
$V_{BB} = 1.8\ \text{V}$

$V_E = V_{BB} - V_{BE}$
$V_E = 1.8\ \text{V} - 0.7\ \text{V}$
$V_E = 1.1\ \text{V}$

$I_E = V_E/R_E$
$I_E = 1.1\ \text{V}/1\ \text{k}\Omega$
$I_E = 1.1\ \text{mA}$

$r_e' = (25\ \text{mV})/I_E$
$r_e' = (25\ \text{mV})/1.1\ \text{mA}$
$r_e' = 22.7\ \Omega$

$r_c = R_C \| R_L$
$r_c = 3.6\ \text{k}\Omega \| 10\ \text{k}\Omega$
$r_c = 2.65\ \text{k}\Omega$

$A_\text{v} = r_c / r_e'$
$A_\text{v} = 2.65\ \text{k}\Omega/22.7\ \Omega$
$A_\text{v} = 117$

$z_\text{in} = R_1 \| R_2 \| \beta r_e'$
$z_\text{in} = 10\ \text{k}\Omega \| 2.2\ \text{k}\Omega \| 2.27\ \text{k}\Omega$
$z_\text{in} = 1\ \text{k}\ \Omega$

$v_\text{in} = [z_\text{in}/(R_G + z_\text{in})]v_g$
$v_\text{in} = [1\ \text{k}\Omega/(300\ \Omega + 1\ \text{k}\Omega)]1\ \text{mV}$
$v_\text{in} = 769\ \mu\text{V}$

$v_\text{out} = A\text{v}(v_\text{in})$

$v_{out} = 117(769\ \mu V)$
$v_{out} = 90$ mV

Answer: The voltage gain is 117, the output voltage is 90 mV.

10-7. *Given:*

$R_1 = 10$ kΩ
$R_2 = 2.2$ kΩ
$R_C = 3.6$ kΩ
$R_E = 1$ kΩ
$R_L = 10$ kΩ
$R_G = 600$ Ω
$V_{CC} = 10$ V
$V_{BE} = 0.7$ V
$\beta = 100$

Solution:

$V_{BB} = [R_2/(R_1 + R_2)]V_{CC}$ (Eq. 8-1)
$V_{BB} = [2.2\ k\Omega/(10\ k\Omega + 2.2\ k\Omega)]10$ V
$V_{BB} = 1.8$ V

$V_E = V_{BB} - V_{BE}$ (Eq. 8-2)
$V_E = 1.8\ V - 0.7$ V
$V_E = 1.1$ V

$I_E = V_E/R_E$ (Eq. 8-3)
$I_E = 1.1\ V/1$ kΩ
$I_E = 1.1$ mA

$r_e' = (25\ mV)/I_E$ (Eq. 9-10)
$r_e' = (25\ mV)/1.1$ mA
$r_e' = 22.7$ Ω

$z_{in} = R_1 \| R_2 \| \beta r_e'$
$z_{in} = 10\ k\Omega \| 2.2\ k\Omega \| 100(22.7\ \Omega)$
$z_{in} = 1.0$ kΩ

The input impedance for each stage is 1.0 kΩ.

$v_{in(1)} = [z_{in}/(R_G + z_{in})]v_g$ (Eq. 10-4)
$v_{in(1)} = [1.0\ k\Omega/(600\ \Omega + 1.0\ k\Omega)]1$ mV
$v_{in(1)} = 0.625$ mV

The input impedance for the second stage is the load resistance for the first stage.

$r_C = R_C \| R_L$ (Eq. 10-2)
$r_c = 3.6\ k\Omega \| 1.0$ kΩ
$r_c = 783$ Ω

$A_v = r_e / r_e'$ (Eq. 10-3)
$A_v = 783\ \Omega/22.7$ Ω
$A_v = 34.5$

The output voltage of the first stage is the input voltage for the second stage.

$v_{out(1)} = A_v(v_{in})$
$v_{out(1)} = 34.5(0.625$ mV$)$
$v_{out(1)} = 21.6$ mV

$r_{c(2)} = R_C \| R_L$ (Eq. 10-2)
$r_{c(2)} = 3.6\ k\Omega \| 10$ kΩ
$r_{c(2)} = 2.65$ kΩ

$A_{v(2)} = r_c / r_e'$ (Eq. 10-3)
$A_{v(2)} = 2.65\ k\Omega/22.7\Omega$
$A_{v(2)} = 117$

$v_{out(2)} = A_v(v_{in})$
$v_{out(2)} = 117(21.6$ mV$)$
$v_{out(2)} = 2.53$ V

Answer: The base voltage of the first stage is 0.625 mV, the base voltage of the second stage is 21.6 mV, and the voltage across the collector resistor is 2.53 V.

10-8. *Given:*

$R_1 = 10$ kΩ
$R_2 = 2.2$ kΩ
$R_C = 3.6$ kΩ
$R_E = 1$ kΩ
$R_L = 10$ kΩ
$R_G = 600$ Ω
$V_{CC} = 12$ V
$V_{BE} = 0.7$ V
$\beta = 100$

Solution:

$V_{BB} = [R_2/(R_1 + R_2)]V_{CC}$ (Eq. 8-1)
$V_{BB} = [2.2\ k\Omega/(10\ k\Omega + 2.2\ k\Omega)]12$ V
$V_{BB} = 2.16$ V

$V_E = V_{BB} - V_{BE}$ (Eq. 8-2)
$V_E = 2.16\ V - 0.7$ V
$V_E = 1.46$ V

$I_E = V_E / R_E$ (Eq. 8-3)
$I_E = 1.46\ V/1$ kΩ
$I_E = 1.46$ mA

$r_e' = (25\ mV)/I_E$ (Eq. 9-10)
$r_e' = (25\ mV)/1.46$ mA
$r_e' = 17.1$ Ω

$z_{in} = R_1 \| R_2 \| \beta r_e'$
$z_{in} = 10\ k\Omega \| 2.2\ k\Omega \| 100(17.1\ \Omega)$
$z_{in} = 878$ Ω

The input impedance for each stage is 878 Ω.

$v_{in(1)} = [z_{in}/(R_G + z_{in})]\ v_g$ (Eq. 10-4)
$v_{in(1)} = (878\ \Omega/\ (600\ \Omega + 878\ \Omega)]1$ mV
$v_{in(1)} = 0.594$ mV

The input impedance for the second stage is the load resistance for the first stage.

$r_c = R_C \| R_L$ (Eq. 10-2)
$r_c = 3.6\ k\Omega \| 878$ Ω
$r_c = 706$ Ω

$A_v = r_c / r_e'$ (Eq. 10-7)
$A_v = 706\ \Omega/17.1$ Ω
$A_v = 41.3$

The output voltage of the first stage is the input voltage for the second stage.

$v_{out(1)} = Av_{in}$
$v_{out(1)} = 41.3(0.594$ mV$)$
$v_{out(1)} = 24.5$ mV

$r_{c(2)} = R_C \| R_L$ (Eq. 10-2)
$r_{c(2)} = 3.6\ k\Omega \| 10$ kΩ
$r_{c(2)} = 2.65$ kΩ

$A_{v(2)} = r_c / r_e'$ (Eq. 10-7)
$A_{v(2)} = 2.65\ k\Omega/17.1$ Ω
$A_{v(2)} = 155$

$v_{out(2)} = A_v(v_{in})$
$v_{out(2)} = 155(24.5$ mV$)$
$v_{out(2)} = 3.80$ V

Answer: The output voltage is 3.80 V.

10-9. *Given:*

$R_1 = 10$ kΩ
$R_2 = 2.2$ kΩ
$R_C = 3.6$ kΩ
$R_E = 1$ kΩ
$R_L = 10$ kΩ
$R_G = 600$ Ω

$V_{CC} = 10$ V
$V_{BE} = 0.7$ V
$\beta = 300$

Solution:

$V_{BB} = [R_2/(R_1 + R_2)]V_{CC}$ (Eq. 8-1)
$V_{BB} = [2.2\ \text{k}\Omega/(10\ \text{k}\Omega + 2.2\ \text{k}\Omega)]10$ V
$V_{BB} = 1.8$ V

$V_E = V_{BB} - V_{BE}$ (Eq. 8-2)
$V_E = 1.8\text{ V} - 0.7$ V
$V_E = 1.1$ V

$I_E = V_E/R_E$ (Eq. 8-3)
$I_E = 1.1\text{ V}/1\ \text{k}\Omega$
$I_E = 1.1$ mA

$r_e' = (25\text{ mV})/I_E$ (Eq. 9-10)
$r_e' = (25\text{ mV})/1.1\text{ mA}$
$r_e' = 22.7\ \Omega$

$z_{\text{in}} = R_1 \| R_2 \| \beta r_e'$
$z_{\text{in}} = 10\ \text{k}\Omega \| 2.2\ \text{k}\Omega \| 300(22.7\ \Omega)$
$z_{\text{in}} = 1.43\ \text{k}\Omega$

The input impedance for each stage is 1.43 kΩ.

$v_{\text{in}(1)} = [z_{\text{in}}/(R_G + z_{\text{in}})]v_g$ (Eq. 10-4)
$v_{\text{in}(1)} = [1.43\ \text{k}\Omega/(600\ \Omega + 1.43\ \text{k}\Omega)]1$ mV
$v_{\text{in}(1)} = 0.704$ mV

The input impedance for the second stage is the load resistance for the first stage.

$r_c = R_C \| R_L$ (Eq. 10-2)
$r_c = 3.6\ \text{k}\Omega \| 1.43\ \text{k}\Omega$
$r_c = 1.02\ \text{k}\Omega$

$A_v = r_c / r_e'$ (Eq. 10-3)
$A_v = 1.02\ \text{k}\Omega/22.7\ \Omega$
$A_v = 45$

The output voltage of the first stage is the input voltage for the second stage.

$v_{\text{out}(1)} = A_v\,(v_{\text{in}})$
$v_{\text{out}(1)} = 45(0.704\text{ mV})$
$v_{\text{out}(1)} = 31.7$ mV

$r_{c(2)} = R_C \| R_L$ (Eq. 10-2)
$r_{c(2)} = 3.6\ \text{k}\Omega \| 10\ \text{k}\Omega$
$r_{c(2)} = 2.65\ \text{k}\Omega$

$A_{v(2)} = r_c / r_e'$ (Eq. 10-3)
$A_{v(2)} = 2.65\ \text{k}\Omega/22.7\ \Omega$
$A_{v(2)} = 117$

$v_{\text{out}(2)} = Av_{\text{in}}$
$v_{\text{out}(2)} = 117\ (31.7\text{ mV})$
$v_{\text{out}(2)} = 3.71$ V

Answer: The output voltage is 3.71 V.

10-10. *Given:*

$R_1 = 10\ \text{k}\Omega$
$R_2 = 2.2\ \text{k}\Omega$
$R_C = 3.6\ \text{k}\Omega$
$R_E = 820\ \Omega$
$r_e = 180\ \Omega$
$R_L = 10\ \text{k}\Omega$
$R_G = 600\ \Omega$
$V_{BE} = 0.7$ V
$V_{CC} = 10$ V
Assume $\beta = 100$

Solution:

$r_c = R_C \| R_L$
$r_c = 3.6\ \text{k}\Omega \| 10\ \text{k}\Omega$
$r_c = 2.65\ \text{k}\Omega$

$A_v = r_c/r_e$
$A_v = 2.65\ \text{k}\Omega/180\ \Omega$
$A_v = 14.7$

$z_{\text{in}} = R_1 \| R_2 \| \beta r_c$
$z_{\text{in}} = 10\ \text{k}\Omega \| 2.2\ \text{k}\Omega \| 18\ \text{k}\Omega$
$z_{\text{in}} = 1.64\ \text{k}\Omega$

$v_{\text{in}} = [z_{\text{in}}/(R_G + z_{\text{in}})]v_g$
$v_{\text{in}} = [1.64\ \text{k}\Omega/(600\ \Omega + 1.64\ \text{k}\Omega)]25$ mV
$v_{\text{in}} = 18.3$ mV

$v_{\text{out}} = A_v(v_{\text{in}})$
$v_{\text{out}} = 14.7(18.3\text{ mV})$
$v_{\text{out}} = 269$ mV

Answer: The voltage gain is 14.7, the output voltage is 269 mV.

10-11. *Given:*

$R_1 = 10\ \text{k}\Omega$
$R_2 = 2.2\ \text{k}\Omega$
$R_C = 3.6\ \text{k}\Omega$
$R_E = 820\ \Omega$
$r_e = 180\ \Omega$
$R_L = 10\ \text{k}\Omega$
$R_G = 50\ \Omega$
$V_{BE} = 0.7$ V
$V_{CC} = 10$ V
Assume $\beta = 100$

Solution:

$r_c = R_C \| R_L$
$r_c = 3.6\ \text{k}\Omega \| 10\ \text{k}\Omega$
$r_c = 2.65\ \text{k}\Omega$

$A_v = r_c/r_e$
$A_v = 2.65\ \text{k}\Omega/180\ \Omega$
$A_v = 14.7$

$z_{\text{in}} = R_1 \| R_2 \| \beta r_e$
$z_{\text{in}} = 10\ \text{k}\Omega \| 2.2\ \text{k}\Omega \| 18\ \text{k}\Omega$
$z_{\text{in}} = 1.64\ \text{k}\Omega$

$v_{\text{in}} = [z_{\text{in}}/(R_G + z_{\text{in}})]v_g$
$v_{\text{in}} = [1.64\ \text{k}\Omega/(50\ \Omega + 1.64\ \text{k}\Omega)]50$ mV
$v_{\text{in}} = 48.52$ mV

$v_{\text{out}} = A_v(v_{\text{in}})$
$v_{\text{out}} = 14.7(48.52\text{ mV})$
$v_{\text{out}} = 713$ mV

Answer: The voltage gain is 14.7, the output voltage is 713 mV.

10-12. *Given:*

$R_1 = 10\ \text{k}\Omega$
$R_2 = 2.2\ \text{k}\Omega$
$R_C = 3.6\ \text{k}\Omega$
$R_E = 820\ \Omega$
$r_e = 180\ \Omega$
$R_L = 3.6\ \text{k}\Omega$
$R_G = 600\ \Omega$
$V_{BE} = 0.7$ V
$V_{CC} = 10$ V
Assume $\beta = 100$

Solution:

$r_c = R_C \| R_L$
$r_c = 3.6\ \text{k}\Omega \| 3.6\ \text{k}\Omega$
$r_c = 1.8\ \text{k}\Omega$

$A_v = r_c/r_e$
$A_v = 1.8\ \text{k}\Omega/180\ \Omega$
$A_v = 10$

Answer: The voltage gain is 10.

10-13. *Given:*

$R_1 = 10\ \text{k}\Omega$
$R_2 = 2.2\ \text{k}\Omega$
$R_C = 3.6\ \text{k}\Omega$
$R_E = 820\ \Omega$
$r_e = 180\ \Omega$
$R_L = 10\ \text{k}\Omega$
$R_G = 600\ \Omega$
$V_{CC} = 30\ \text{V}$
$V_{BE} = 0.7\ \text{V}$

Solution:

$r_c = R_C \| R_L$ (Eq. 10-2)
$r_c = 3.6\ \text{k}\Omega \| 10\ \text{k}\Omega$
$r_c = 2.65\ \text{k}\Omega$

$A_v = r_c / r_e$ (Eq. 10-7)
$A_v = 2.65\ \text{k}\Omega/180\ \Omega$
$A_v = 14.7$

Answer: The voltage gain is 14.7.

10-14. *Given:*

$r_f = 5\ \text{k}\Omega$
$r_e = 50\ \Omega$

Solution:

$A_v = r_f / r_e$ (Eq. 10-10)
$A_v = 5\ \text{k}\Omega/50\ \Omega$
$A_v = 100$

Answer: The voltage gain is 100.

10-15. *Given:*

$r_e = 125\ \Omega$
$A_v = 100$

Solution:

$A_v = r_f / r_e$ (Eq. 10-10)
$r_f = 100(125\ \Omega)$
$r_f = 12.5\ \text{k}\Omega$

Answer: The feedback resistor would need to be 12.5 kΩ.

10-16. *Answer:* Since the capacitor is an open to direct current, the dc voltages do not change. The first stage is now swamped. Therefore the voltage gain is greatly reduced and the input impedance is increased so that more of the generator voltage is seen at the input. The overall effect is a reduced input voltage to the second stage. Since the gain of the second stage remains the same and the input voltage is reduced, the output voltage is also reduced.

10-17. *Answer:* Since there is a voltage at the second stage input, the cause is most likely in the second stage. Some of the possible causes are: open transistor, open emitter resistor, open collector resistor, or open output coupling capacitor.

CRITICAL THINKING

10-18. *Given:*

$R_1 = 20\ \text{k}\Omega$
$R_2 = 4.4\ \text{k}\Omega$
$R_C = 7.2\ \text{k}\Omega$
$R_E = 2\ \text{k}\Omega$
$R_L = 20\ \text{k}\Omega$
$V_{CC} = 10\text{V}$
$V_{BE} = 0.7\ \text{V}$

Solution:

$V_{BB} = [R_2/(R_1 + R_2)]V_{CC}$ (Eq. 8-1)
$V_{BB} = [4.4\ \text{k}\Omega/(20\ \text{k}\Omega + 4.4\ \text{k}\Omega)]10\ \text{V}$
$V_{BB} = 1.8\text{V}$

$V_E = V_{BB} - V_{BE}$ (Eq. 8-2)
$V_E = 1.8\text{V} - 0.7\text{V}$
$V_E = 1.1\ \text{V}$

$I_E = V_E/R_E$ (Eq. 8-3)
$I_E = 1.1\ \text{V}/2\ \text{k}\Omega$
$I_E = 0.55\ \text{mA}$

$r_e' = (25\ \text{mV})/I_E$ (Eq. 9-10)
$r_e' = (25\ \text{mV})/0.55\ \text{mA}$
$r_e' = 45.5\ \Omega$

$r_c = R_C \| R_L$ (Eq. 10-2)
$r_c = 7.2\ \text{k}\Omega \| 20\ \text{k}\Omega$
$r_c = 5.3\ \text{k}\Omega$

$A_v = r_c / r_e'$ (Eq. 10-3)
$A_v = 5.3\ \text{k}\Omega/45.5\ \Omega$
$A_v = 116$

Answer: The voltage gain is 116.

10-19. *Given:*

$R_1 = 20\ \text{k}\Omega$
$R_2 = 4.4\ \text{k}\Omega$
$R_C = 7.2\ \text{k}\Omega$
$R_E = 2\ \text{k}\Omega$
$R_L = 20\ \text{k}\Omega$
$R_G = 1.2\ \text{k}\Omega$
$V_{CC} = 10\ \text{V}$
$V_{BE} = 0.7\ \text{V}$
Assume $\beta = 100$
$V_{BB} = 1.8\ \text{V}$ (from Prob. 10-18)
$V_E = 1.1\ \text{V}$ (from Prob. 10-18)
$I_E = 0.55\ \text{mA}$ (from Prob. 10-18)
$r_e' = 45.5\ \Omega$ (from Prob. 10-18)
$r_c' = 5.3\ \text{k}\Omega$
$A_v = 116$

Solution:

$z_{in} = R_1 \| R_2 \| \beta r_e'$
$z_{in} = 20\ \text{k}\Omega \| 4.4\ \text{k}\Omega \| 100(45.5\ \Omega)$
$z_{in} = 2.01\ \text{k}\Omega$

$v_{in} = [z_{in}/(R_G + z_{in})]v_g$ (Eq. 10-4)
$v_{in} = [2.01\ \text{k}\Omega/(1.2\ \text{k}\Omega + 2.01\ \text{k}\Omega)]1\ \text{mV}$
$v_{in} = 0.626\ \text{mV}$

$v_{out} = A_v(v_{in})$
$v_{out} = 116(0.626\ \text{mV})$
$v_{out} = 72.6\ \text{mV}$

Answer: The output voltage is 72.6 mV.

10-20. *Given:*

$R_1 = 20\ \text{k}\Omega$
$R_2 = 4.4\ \text{k}\Omega$
$R_C = 7.2\ \text{k}\Omega$
$R_E = 2\ \text{k}\Omega$
$R_L = 20\ \text{k}\Omega$
$R_G = 1.2\ \text{k}\Omega$
$V_{CC} = 10\ \text{V}$
$V_{BB} = 0.7\ \text{V}$
$\beta = 100$

Solution:

$V_{BB} = [R_2/(R_1 + R_2)]V_{CC}$ (Eq. 8-1)
$V_{BB} = [4.4\ \text{k}\Omega/(20\ \text{k}\Omega + 4.4\ \text{k}\Omega)]\ 10\ \text{V}$
$V_{BB} = 1.8\ \text{V}$

$V_E = V_{BB} - V_{BE}$ (Eq. 8-2)
$V_E = 1.8\ \text{V} - 0.7\ \text{V}$
$V_E = 1.1\ \text{V}$

$I_E = V_E/R_E$ (Eq. 8-3)
$I_E = 1.1\ \text{V}/2\ \text{k}\Omega$
$I_E = 0.55\ \text{mA}$

$r'_e = (25\ \text{mV})/I_E$ (Eq. 9-10)
$r'_e = (25\ \text{mV})/0.55\ \text{mA}$
$r'_e = 45.5\ \Omega$

$z_{\text{in}} = R_1 \parallel R_2 \parallel \beta r'_e$
$z_{\text{in}} = 20\ \text{k}\Omega \| 4.4\ \text{k}\Omega \| 100(45.5\ \Omega)$
$z_{\text{in}} = 2.01\ \text{k}\Omega$

The input impedance for each stage is 2.01 kΩ.

$v_{\text{in(1)}} = [z_{\text{in}}/(R_G + z_{\text{in}})]v_g$ (Eq. 10-4)
$v_{\text{in(1)}} = [2.01\ \text{k}\Omega/(1.2\ \text{k}\Omega + 2.01\ \text{k}\Omega)]1\ \text{mV}$
$v_{\text{in(1)}} = 0.626\ \text{mV}$

The input impedance for the second stage is the load resistance for the first stage.

$r_c = R_C \| R_L$ (Eq. 10-2)
$r_c = 3.6\ \text{k}\Omega \| 2.01\ \Omega$
$r_c = 1.29\ \text{k}\Omega$

$A_v = r_c / r'_e$ (Eq. 10-3)
$A_v = 1.29\ \text{k}\Omega/45.5\ \Omega$
$A_v = 28.4$

The output voltage of the first stage is the input voltage for the second stage.

$v_{\text{out(1)}} = A_v(v_{\text{in}})$
$v_{\text{out(1)}} = 28.4(0.626\ \text{mV})$
$v_{\text{out(1)}} = 17.8\ \text{mV}$

$r_{c(2)} = R_C \| R_L$ (Eq. 10-2)
$r_{c(2)} = 7.2\ \text{k}\Omega \| 20\ \text{k}\Omega$
$r_{c(2)} = 5.3\ \text{k}\Omega$

$A_{v(2)} = r_c / r'_e$ (Eq. 10-3)
$A_{v(2)} = 5.3\ \text{k}\Omega/45.5\ \Omega$
$A_{v(2)} = 116$

$v_{\text{out(2)}} = A_v(v_{\text{in}})$
$v_{\text{out(2)}} = 116(17.8\ \text{mV})$
$v_{\text{out(2)}} = 2.06\ \text{V}$

Answer: The output voltage is 2.06 V.

10-21. *Answer:* The r_c would be the collector resistance only: 3.6 kΩ.

10-22. *Answers:*

Trouble 1: Since all the ac voltages are 0, the problem could be the generator, R_G open, or C_1 open.

Trouble 2: Since the input voltage increased to 0.75 mV, the problem is an open R_E.

Trouble 3: Since there are no ac voltages and the base voltage has changed, the problem is in the input circuit. Since there is a 0.7-V drop across the *BE* diode, the transistor should be conducting and thus the collector voltage should be less than 10V. It appears that the *BC* diode is open, except the base voltages are not consistent with that problem. To make this problem correct for the *BC* diode open, return V_B, V_E, and v_b to the OK values.

Trouble 4: Since the dc base voltage is 0 and there is an ac base voltage, the problem is an R_1 open.

10-23. *Answers:*

Trouble 5: Since there is no output ac voltage, the problem is C_2 open.

Trouble 6: Since there are no ac voltages and the base voltage has changed, the problem is in the input circuit. The voltage points to an open R_2.

Trouble 7: All the dc voltages are OK; thus the transistor and resistors are OK. Since the base and emitter ac voltages are the same, the problem appears to be an open bypass capacitor C_3.

Trouble 8: Since there are no ac voltages and the base voltage has changed, the problem is in the input circuit. Since the collector voltage is so low, the collector resistor is open.

10-24. *Answers:*

Trouble 9: Since there are no dc voltages, the problem is no V_{CC}.

Trouble 10: Since the emitter voltage is 0 and the base voltage is near normal, the problem is an open *BE* diode.

Trouble 11: With all the dc voltages the same, the problem is a shorted transistor in all three terminals.

Trouble 12: Since all the ac voltages are 0, the problem could be the generator, R_G open, or C_1 open.

Chapter 11 CC and CB Amplifiers

SELF-TEST

1. b	**9. d**	**17. a**	**25. a**
2. c	**10. c**	**18. c**	**26. c**
3. b	**11. a**	**19. c**	**27. d**
4. c	**12. c**	**20. a**	**28. c**
5. d	**13. d**	**21. a**	**29. b**
6. c	**14. a**	**22. d**	**30. d**
7. a	**15. c**	**23. a**	
8. a	**16. c**	**24. d**	

JOB INTERVIEW QUESTIONS

5. Voltage gain is always less than but usually near 1. The circuit is used as a current or power amplifier. Applications include stereo output stages, linear power-supply regulation, and drivers for relays, LEDs.

7. They allow excellent impedance matching and maximum power transfer to low-impedance loads.

11. None.

12. Power gain is the product of voltage gain and current gain. Although the voltage gain is slightly less than 1, the current gain is very large. Therefore, the power gain is very large.

PROBLEMS

11-1. *Given:*

$R_1 = 2.2\ \text{k}\Omega$
$R_2 = 2.2\ \text{k}\Omega$
$R_E = 1\ \text{k}\Omega$
$R_L = 3.3\ \text{k}\Omega$
$R_G = 50\ \Omega$
$\beta = 200$
$V_{CC} = 15\ \text{V}$
$V_{BE} = 0.7\ \text{V}$

Solution:

$V_{BB} = [R_2/(R_1 + R_2)]V_{CC}$ (Eq. 8-1)
$V_{BB} = [2.2\text{ k}\Omega/(2.2\text{ k}\Omega + 2.2\text{ k}\Omega)]15\text{ V}$
$V_{BB} = 7.5\text{ V}$

$V_E = V_{BB} - V_{BE}$ (Eq. 8-2)
$V_E = 7.5\text{ V} - 0.7\text{ V}$
$V_E = 6.8\text{ V}$

$I_E = V_E/R_E$ (Eq. 8-3)
$I_E = 6.8\text{ V}/1\text{ k}\Omega$
$I_E = 6.8\text{ mA}$

$r'_e = 25\text{ mV}/I_E$ (Eq. 9-10)
$r'_e = 25\text{ mV}/6.8\text{ mA}$
$r'_e = 3.68\ \Omega$

$r_e = R_E \| R_L$ (Eq. 11-1)
$r_e = 1\text{ k}\Omega \| 3.3\text{ k}\Omega$
$r_e = 767\ \Omega$

$z_{\text{in(baSe)}} = \beta(r_e + r'_e)$ (Eq. 11-3)
$z_{\text{in(base)}} = 200(767\ \Omega + 3.48\ \Omega)$
$z_{\text{in(base)}} = 154\text{ k}\Omega$
$z_{\text{in(base)}} = 154\text{ k}\Omega \| 2.2\text{ k}\Omega \| 2.2\text{ k}\Omega = 1.09\text{ k}\Omega$

Answer: The input impedance of the base is 154 kΩ, and the input impedance of the stage is 1.09 kΩ.

11-2. *Given:*

$R_1 = 2.2\text{ k}\Omega$
$R_2 = 2.2\text{ k}\Omega$
$R_E = 1\text{ k}\Omega$
$R_L = 3.3\text{ k}\Omega$
$R_G = 50\ \Omega$
$\beta = 150$
$V_{CC} = 15\text{ V}$
$V_{BE} = 0.7\text{ V}$
$r'_e = 3.68\ \Omega$ (from Prob. 11-1)
$r_e = 767\ \Omega$ (from Prob. 11-1)

Solution:

$z_{\text{in}} = R_1 \| R_2 \| \beta(r_e + r'_e)$ (Eq. 11-4)
$z_{\text{in}} = 2.2\text{ k}\Omega \| 2.2\text{ k}\Omega \| 150(767\ \Omega + 3.48\ \Omega)$
$z_{\text{in}} = 1.09\text{ k}\Omega$

$v_{\text{in}} = [z_{\text{in}}/(z_{\text{in}} + R_{\text{G}})]V_{\text{G}}$
$v_{\text{in}} = [1.09\text{ k}\Omega/(1.09\text{ k}\Omega + 50\ \Omega)]1\text{ V}$
$v_{\text{in}} = 0.956\text{ V}$

Answer: The input voltage is 0.956 V.

11-3. *Given:*

$R_1 = 2.2\text{ k}\Omega$
$R_2 = 2.2\text{ k}\Omega$
$R_E = 1\text{ k}\Omega$
$R_L = 3.3\text{ k}\Omega$
$R_G = 50\ \Omega$
$\beta = 175$
$V_{CC} = 15\text{V}$
$V_{BE} = 0.7\text{ V}$
$r'_e = 3.68\ \Omega$ (from Prob. 11-1)
$r_e = 767\ \Omega$ (from Prob. 11 − 1)

Solution:

$A_\text{v} = r_e/(r_e + r'_e)$ (Eq. 11-2)
$A_\text{v} = 767/(767 + 3.48)$
$A_\text{v} = 0.995$

$z_{\text{in}} = R_1 \| R_2 \| \beta(r_e + r'_e)$ (Eq. 11-4)
$z_{\text{in}} = 2.2\text{ k}\Omega \| 2.2\text{ k}\Omega \| 175(767\ \Omega + 3.48\ \Omega)$
$z_{\text{in}} = 1.09\text{ k}\Omega$

$v_{\text{in}} = [z_{\text{in}}/(z_{\text{in}} + R_G)]V_G$
$v_{\text{in}} = [1.09\text{ k}\Omega/(1.09\text{ k}\Omega + 50\ \Omega)]1\text{ V}$
$v_{\text{in}} = 0.956\text{ V}$

$v_{\text{out}} = A_\text{v}(v_{\text{in}})$ (Eq. 9-3)
$v_{\text{out}} = (0.995)(0.956\text{ V})$
$v_{\text{out}} = 0.951\text{ V}$

Answer: The gain is 0.995, and the output voltage is 0.951 V.

11-4. *Given:*

$R_1 = 2.2\text{ k}\Omega$
$R_2 = 2.2\text{ k}\Omega$
$R_E = 1\text{ k}\Omega$
$R_L = 3.3\text{ k}\Omega$
$R_G = 50\ \Omega$
$\beta = 50$ to 300
$V_{CC} = 15\text{ V}$
$V_{BE} = 0.7\text{ V}$
$r'_e = 3.68\ \Omega$ (from Prob. 11-1)
$r_e = 767\ \Omega$ (from Prob. 11-1)

Solution:

$z_{\text{in(min)}} = R_1 \| R_2 \| \beta(r_e + r'_e)$ (Eq. 11-4)
$z_{\text{in(min)}} = 2.2\text{ k}\Omega \| 2.2\text{ k}\Omega \| 50(767\ \Omega + 3.48\ \Omega)$
$z_{\text{in(min)}} = 1.07\text{ k}\Omega$

$z_{\text{in(max)}} = R_1 \| R_2 \| \beta(r_e + r'_e)$ (Eq. 11-4)
$z_{\text{in(max)}} = 2.2\text{ k}\Omega \| 2.2\text{ k}\Omega \| 300(767\ \Omega + 3.48\ \Omega)$
$z_{\text{in(max)}} = 1.09\text{ k}\Omega$

$v_{\text{in(min)}} = [z_{\text{in}}/(z_{\text{in}} + R_G)]V_G$
$v_{\text{in(min)}} = [1.07\text{ k}\Omega/(1.07\text{ k}\Omega + 50\ \Omega)]1\text{ V}$
$v_{\text{in(min)}} = 0.955\text{ V}$

$v_{\text{in(min)}} = [z_{\text{in}}/(z_{\text{in}} + R_G)]V_G$
$v_{\text{in(min)}} = [1.09\text{ k}\Omega/(1.09\text{ k}\Omega + 50\ \Omega)]1\text{ V}$
$v_{\text{in(min)}} = 0.956\text{ V}$

Answer: The input voltage varies over the range of 0.955 to 0.956 V.

11-5. *Given:*

$R_1 = 4.4\text{ k}\Omega$
$R_2 = 4.4\text{ k}\Omega$
$R_E = 2\text{ k}\Omega$
$R_L = 6.6\text{ k}\Omega$
$R_G = 100\ \Omega$
$\beta = 150$
$V_{CC} = 15\text{ V}$
$V_{BE} = 0.7\text{ V}$

Solution:

$V_{BB} = [R_2/(R_1 + R_2)]V_{CC}$ (Eq. 8-1)
$V_{BB} = [4.4\text{ k}\Omega/(4.4\text{ k}\Omega + 4.4\text{ k}\Omega)]15\text{ V}$
$V_{BB} = 7.5\text{ V}$

$V_E = V_{BB} - V_{BE}$ (Eq. 8-2)
$V_E = 7.5\text{ V} - 0.7\text{ V}$
$V_E = 6.8\text{ V}$

$I_E = V_E/R_E$ (Eq. 8-3)
$I_E = 6.8\text{ V}/2\text{ k}\Omega$
$I_E = 3.4\text{ mA}$

$r'_e = 25\text{ mV}/I_E$ (Eq. 9-10)
$r'_e = 25\text{ mV}/3.4\text{ mA}$
$r'_e = 7.35\ \Omega$

$r_e = R_E \| R_L$ (Eq. 11-1)
$r_e = 2\text{ k}\Omega \| 6.6\text{ k}\Omega$
$r_e = 1.53\text{ k}\Omega$

$z_{in} = R_1 \,||\, R_2 \,||\, \beta(r_e + r'_e)$ (Eq. 11-4)
$z_{in} = 4.4\ k\Omega \| 4.4\ k\Omega \| 150(1.53\ k\Omega + 7.35\ k\Omega)$
$z_{in} = 2.18\ k\Omega$

$v_{in} = [z_{in}/(z_{in} + R_G)]V_G$
$v_{in} = [2.18\ k\Omega/(2.18\ k\Omega + 100\ \Omega)]1\ V$
$v_{in} = 0.956\ V$

Answer: The input impedance doubles to 2.18 kΩ, and the input voltage remains the same at 0.956 V.

11-6. *Given:*

$R_1 = 100\ \Omega$
$R_2 = 200\ \Omega$
$R_E = 30\ \Omega$
$R_L = 10\ \Omega$
$R_G = 50\ \Omega$
$\beta = 200$
$V_{CC} = 20\ V$
$V_{BE} = 0.7\ V$

Solution:

$V_{BB} = [R_2/(R_1 + R_2)]V_{CC}$ (Eq. 8-1)
$V_{BB} = [200\ \Omega/(100\ \Omega + 200\ \Omega)]20\ V$
$V_{BB} = 13.3\ V$

$V_E = V_{BB} - V_{BE}$ (Eq. 8-2)
$V_E = 13.3\ V - 0.7\ V$
$V_E = 12.6\ V$

$I_E = V_E/R_E$ (Eq. 8-3)
$I_E = 12.6\ V/30\ \Omega$
$I_E = 420\ mA$

$r'_e = 25\ mV / I_E$ (Eq. 9-10)
$r'_e = 25\ mV / 420\ mA$
$r'_e = 0.06\ \Omega$

$r_e = R_E \| R_L$ (Eq. 11-1)
$r_e = 30\ \Omega \| 10\ \Omega$
$r_e = 7.5\ \Omega$

$z_{in(base)} = \beta(r_e + r'_e)$ (Eq. 11-3)
$z_{in(base)} = 200(7.5\ \Omega + 0.06\ \Omega)$
$z_{in(base)} = 1.51\ k\Omega$

$z_{in} = R_1 \,||\, R_2 \,||\, \beta(r_e + r'_e)$ (Eq. 11-4)
$z_{in} = 100\ \Omega \| 200\ \Omega \| 1.51\ k\Omega$
$z_{in} = 63.8\ \Omega$

Answer: The input impedance of the base is 1.51 kΩ, and the input impedance to the stage is 63.8 Ω.

11-7. *Given:*

$R_1 = 100\ \Omega$
$R_2 = 200\ \Omega$
$R_E = 30\ \Omega$
$R_L = 50\ \Omega$
$R_G = 50\ \Omega$
$\beta = 150$
$V_{CC} = 20\ V$
$V_{BE} = 0.7\ V$
$r'_e = 0.06\ \Omega$ (from Prob.11-6)
$r_e = 7.5\ \Omega$ (from Prob. 11-6)

Solution:

$z_{in} = R_1 \,||\, R_2 \,||\, \beta(r_e + r'_e)$ (Eq. 11-4)
$z_{in} = 100\ \Omega \| 200\ \Omega \| 150(7.5\ \Omega + 0.06\ \Omega)$
$z_{in} = 63\ \Omega$

$v_{in} = [z_{in}/(z_{in} + R_G)]V_G$
$v_{in} = [63\ \Omega/(63\ \Omega + 50\ \Omega)]1\ V$
$v_{in} = 0.558\ V$

Answer: The input voltage is 0.558 V.

11-8. *Given:*

$R_1 = 100\ \Omega$
$R_2 = 200\ \Omega$
$R_E = 30\ \Omega$
$R_L = 10\ \Omega$
$R_G = 50\ \Omega$
$\beta = 175$
$V_{CC} = 20\ V$
$V_{BE} = 0.7\ V$
$r'_e = 0.06\ \Omega$ (from Prob. 11-6)
$r_e = 7.5\ \Omega$ (from Prob. 11-6)

Solution:

$A_v = r_e/(r_e + r'_e)$ (Eq. 11-2)
$A_v = 7.5/(7.5 + 0.06)$
$A_v = 0.992$

$z_{in} = R_1 \,||\, R_2 \,||\, \beta(r_e + r'_e)$ (Eq. 11-4)
$z_{in} = 100\ \Omega \| 200\ \Omega \| 175(7.5\ \Omega + 0.06\ \Omega)$
$z_{in} = 63.5\ \Omega$

$v_{in} = [z_{in}/(z_{in} + R_G)]V_G$
$v_{in} = [63.5\ \Omega/(63.5\ \Omega + 50\ \Omega)]1\ V$
$v_{in} = 0.559\ V$

$v_{out} = A_v(v_{in})$ (Eq. 9-3)
$v_{out} = (0.992)(0.559\ V)$
$v_{out} = 0.555\ V$

Answer: The gain is 0.992, and the output voltage is 0.555 V.

11-9. *Given:*

$R_1 = 2.2\ k\Omega$
$R_2 = 2.2\ k\Omega$
$R_E = 1\ k\Omega$
$R_L = 3.3\ k\Omega$
$R_G = 50\ \Omega$
$\beta = 200$
$V_{CC} = 15\ V$
$V_{BE} = 0.7V$
$r'_e = 3.68\ \Omega$ (from Prob. 11-1)
$r_e = 767\ \Omega$ (from Prob. 11-1)

Solution:

$z_{out} = R_E \,||\, [r'_e + (R_G \,||\, R_1 \,||\, R_2)/\beta]$ (Eq. 11-5)
$z_{out} = 1\ k\Omega \| [3.68\ \Omega + (50\ \Omega \| 2.2\ k\Omega \| 2.2\ k\Omega)/200]$
$z_{out} = 3.9\ \Omega$

Answer: The output impedance is 3.9 Ω.

11-10. *Given:*

$R_1 = 100\ \Omega$
$R_2 = 200\ \Omega$
$R_E = 30\ \Omega$
$R_L = 10\ \Omega$
$R_G = 50\ \Omega$
$\beta = 100$
$V_{CC} = 20\ V$
$V_{BE} = 0.7\ V$
$r'_e = 0.06\ \Omega$ (from Prob. 11-6)
$r_e = 7.5\ \Omega$ (from Prob. 11-6)

Solution:

$z_{out} = R_E \,||\, [r'_e + (R_G \,||\, R_1 \,||\, R_2)/\beta$ (Eq. 11-5)
$z_{out} = 30\ \Omega \| [0.06\ \Omega + (50\ \Omega \| 100\ \Omega \| 200\ \Omega)/100]$
$z_{out} = 0.342\ \Omega$

Answer: The output impedance is 0.342 Ω.

$r'_e = (25\text{ mV})/5.85\text{ mA}$
$r'_e = 4.27\ \Omega$

$r_c = R_C \| R_L$
$r_c = 1.5\text{ k}\Omega \| 150\ \Omega$
$r_c = 136.5\ \Omega$

$A_{v1} = r_c / r'_e$
$A_{v1} = 136.5\ \Omega / 4.27\ \Omega$
$A_{v1} = 31.9$

Answer: The voltage gain drops to 31.9.

11-15. *Given:*

$R_1 = 150\text{ k}\Omega$
$R_2 = 150\text{ k}\Omega$
$R_E = 470\ \Omega$
$R_L = 1\text{ k}\Omega$
$R_G = 5.1\text{ k}\Omega$
$V_{CC} = 15\text{ V}$
$\beta = 5000$

Solution:

$r_e = R_E \| R_L$ (Eq. 11-1)
$r_e = 470\ \Omega \| 1\text{ k}\Omega$
$r_e = 320\ \Omega$

$z_{in(base)} = \beta r_e$
$z_{in(base)} = (5000)(320)$
$z_{in(base)} = 1.6\text{ M}\Omega$

Answer: The input impedance of the base is 1.6 MΩ.

11-16. *Given:*

$R_1 = 150\text{ k}\Omega$
$R_2 = 150\text{ k}\Omega$
$R_E = 470\ \Omega$
$R_L = 1\text{ k}\Omega$
$R_G = 5.1\text{ k}\Omega$
$V_{CC} = 15\text{ V}$
$\beta = 7000$
$r_e = 320\ \Omega$ (from Prob. 11-15)

Solution:

$z_{in(base)} = \beta r_e$
$z_{in(base)} = (7000)\ (320)$
$z_{in(base)} = 2.24\text{ M}\Omega$

$z_{in} = R_1 \| R_2 \| z_{in(base)}$ (Eq. 11-4)
$z_{in} = 150\text{ k}\Omega \|\ 150\text{ k}\Omega \| 2.24\text{ M}\Omega$
$z_{in} = 72.6\text{ k}\Omega$

$v_{in} = [z_{in}/(z_{in} + R_G)]V_G$
$v_{in} = [72.6\text{ k}\Omega/(72.6\text{ k}\Omega + 5.1\text{ k}\Omega)]10\text{ mV}$
$v_{in} = 9.34\text{ mV}$

Answer: The input voltage is 9.34 mV.

11-17. *Given:*

$R_1 = 1\text{ k}\Omega$
$R_2 = 2\text{ k}\Omega$
$R_E = 10\ \Omega$
$R_L = 8\ \Omega$
$R_G = 600\ \Omega$
$V_{CC} = 20\text{ V}$
$\beta_1 = 150$
$\beta_2 = 150$

Solution:

$r_e = R_E \| R_L$ (Eq. 11-1)
$r_e = 10\ \Omega \| 8\ \Omega$
$r_e = 4.44\ \Omega$

$\beta = \beta_1\beta_2$ (Eq. 11-7)
$\beta = 150(150)$
$\beta = 22500$
$z_{in(base)} = \beta r_e$
$z_{in(base)} = (22500)(4.44)$
$z_{in(base)} = 100\text{ k}\Omega$

Answer: The input impedance of the base is 100 kΩ.

11-18. *Given:*

$R_1 = 1\text{ k}\Omega$
$R_2 = 2\text{ k}\Omega$
$R_E = 10\ \Omega$
$R_L = 8\ \Omega$
$R_G = 600\ \Omega$
$V_{CC} = 20\text{ V}$
$\beta = 2000$
$r_e = 4.44\ \Omega$ (from Prob. 11-17)

Solution:

$z_{in(base)} = \beta r_e$
$z_{in(base)} = (2000)(4.44)$
$z_{in(base)} = 8.88\text{ k}\Omega$

$z_{in} = R_1 \| R_2 \| z_{in(base)}$ (Eq. 11-8)
$z_{in} = 1\text{ k}\Omega \| 2\text{ k}\Omega \| 8.88\text{ k}\Omega$
$z_{in} = 620\ \Omega$

$v_{in} = [z_{in}/(z_{in} + R_G)]V_G$
$v_{in} = [620\ \Omega/(620\ \Omega + 600\ \Omega)]1\text{ V}$
$v_{in} = 0.508\text{ V}$

Answer: The input voltage is 0.508 V.

11-19. *Given:*

$V_Z = 7.5\text{ V}$
$V_{BE} = 0.7\text{ V}$
$R = 1\text{ k}\Omega$
$V_{CC} = 15\text{V}$

Solution:

$V_{out} = V_Z - V_{BE}$ (Eq. 11-9)
$V_{out} = 7.5\text{ V} - 0.7\text{ V}$
$V_{out} = 6.8\text{ V}$

$I_Z = (V_{CC} - V_Z)/R$
$I_Z = (15 - 7.5)/1\text{ k}\Omega$
$I_Z = 7.5\text{ mA}$

Answer: The output voltage is 6.8 V, and the zener current is 7.5 mA.

11-20. *Given:*

$V_Z = 7.5\text{ V}$
$V_{BE} = 0.7\text{ V}$
$R = 1\text{ k}\Omega$
$V_{CC} = 25\text{ V}$

Solution:

$V_{out} = V_Z - V_{BE}$ (Eq. 11-9)
$V_{out} = 7.5\text{ V} - 0.7\text{ V}$
$V_{out} = 6.8\text{ V}$

Take the base current into account.

$I_Z = (V_{CC} - V_Z)/R - I_{out}/\beta$
$I_Z = (25 - 7.5)/1\text{ k}\Omega - (6.8\text{ V}/33\ \Omega)/150$
$I_Z = 17.5\text{ mA} - 1.37\text{ mA}$
$I_Z = 16.1\text{ mA}$

Answer: The output voltage is 6.8 V, and the zener current is 16.1 mA.

11-21. *Given:* With the wiper in the middle, the voltage divider is effectively two resistors: each has a value of 1.5 kΩ.

$V_Z = 7.5$ V
$V_{BE} = 0.7$ V

Solution:

$V_{out} = [(R_3 + R_4)/R_4](V_Z + V_{BE})$ (Eq. 11-12)
$V_{out} = [(1.5\text{ k}\Omega + 1.5\text{ k}\Omega)/1.5\text{ k}\Omega](7.5\text{ V} + 0.7\text{ V})$
$V_{out} = 16.4$ V

Answer: The output voltage is 16.4 V.

11-22. *Given:* With the wiper all the way up, the voltage divider is effectively two resistors: the top has a value of 1 kΩ, and the bottom has a value of 2 kΩ.

$V_Z = 7.5$ V
$V_{BE} = 0.7$ V

With the wiper all the way down, the voltage divider is effectively two resistors: the top has a value of 2 kΩ, and the bottom has a value of 1 kΩ.

Solution:

$V_{out(top)} = [(R_3 + R_4)/R_4](V_Z + V_{BE})$ (Eq. 11-12)
$V_{out(top)} = [(1\text{ k}\Omega + 2\text{ k}\Omega)/1.5\text{ k}\Omega](7.5\text{ V} + 0.7\text{ V})$
$V_{out(top)} = 12.3$ V

$V_{out(bottom)} = [(R_3 + R_4)/R_4](V_Z + V_{BE})$ (Eq. 11-12)
$V_{out(bottom)} = [(2\text{ k}\Omega + 1\text{ k}\Omega)/1\text{ k}\Omega](7.5\text{ V} + 0.7\text{ V})$
$V_{out(bottom)} = 24.6$ V

Answer: The output voltage with the wiper all the way up is 12.3 V, and all the way down is 24.6 V.

11-23. *Given:*

$R_1 = 10$ kΩ
$R_2 = 2$ kΩ
$R_C = 3.3$ kΩ
$R_E = 2$ kΩ
$V_{CC} = 12$ V

Solution:

$V_{BB} = [R_2/(R_1 + R_2)]V_{CC}$
$V_{BB} = [2\text{ k}\Omega/(10\text{ k}\Omega + 2\text{ k}\Omega)]12\text{ V}$
$V_{BB} = 2$ V

$V_E = V_{BB} - V_{BE}$
$V_E = 2\text{ V} - 0.7\text{ V}$
$V_E = 1.3$ V

$I_E = V_E/R_E$
$I_E = 1.3\text{ V}/2\text{ k}\Omega$
$I_E = 650\ \mu$A

Answer: The emitter current is 650 μA.

11-24. *Given:*

$R_1 = 10$ kΩ
$R_2 = 2$ kΩ
$R_C = 3.3$ kΩ
$R_E = 2$ Ω
$V_{CC} = 12$ V

Solution:

$V_{BB} = [R_2/(R_1 + R_2)]V_{CC}$
$V_{BB} = [2\text{ k}\Omega/(10\text{ k}\Omega + 2\text{ k}\Omega)]12\text{ V}$
$V_{BB} = 2$ V

$V_E = V_{BB} - V_{BE}$
$V_E = 2\text{ V} - 0.7\text{ V}$
$V_E = 1.3$ V

$I_E = V_E/R_E$
$I_E = 1.3\text{ V}/2\text{ k}\Omega$
$I_E = 650\ \mu$A

$r'_e = (25\text{ mV})/I_E$
$r'_e = (25\text{ mV})/650\ \mu\text{A}$
$r'_e = 38.46\ \Omega$

$r_c = R_C \| R_L$
$r_c = 3.3\text{ k}\Omega \| 10\text{ k}\Omega$
$r_c = 2.48$ kΩ

$A_v = r_c / r'_e$
$A_v = 2.48\text{ k}\Omega/38.46\ \Omega$
$A_v = 64.4$

Answer: The voltage gain at 64.4.

11-25. *Given:*

$R_1 = 10$ kΩ
$R_2 = 2$ kΩ
$R_C = 3.3$ kΩ
$R_E = 2$ Ω
$V_{CC} = 12$ V

Solution:

$V_{BB} = [R_2/(R_1 + R_2)]V_{CC}$
$V_{BB} = [2\text{ k}\Omega/(10\text{ k}\Omega + 2\text{ k}\Omega)]12\text{ V}$
$V_{BB} = 2$ V

$V_E = V_{BB} - V_{BE}$
$V_E = 2\text{ V} - 0.7\text{ V}$
$V_E = 1.3$ V

$I_E = V_E/R_E$
$I_E = 1.3\text{ V}/2\text{ k}\Omega$
$I_E = 650\ \mu$A

$r'_e = (25\text{ mV})/I_E$
$r'_e = (25\text{ mV})/650\ \mu\text{A}$
$r'_e = 38.46\ \Omega = 38.5\ \Omega$

$Z_{in(emitter)} = r'_e$

$Z_{in(emitter)} = 38.5\ \Omega$

$Z_{in(Stage)} = R_E \| r'_e$

Since $R_E >> r'_e$

$Z_{in(Stage)} \cong r'_e = 38.5\ \Omega$

$Z_{out} \approx R_C$
$Z_{out} = 3.3$ kΩ

Answer: The $Z_{in(emitter)} = 38.5\Omega$, the $Z_{in(Stage)} = r'_e = 38.5\Omega$, and $Z_{out} = 3.3\text{k}\Omega$.

11-26. *Given:*

$R_1 = 10$ kΩ
$R_2 = 2$ kΩ
$R_C = 3.3$ kΩ
$R_E = 2$ kΩ
$R_G = 50$ Ω
$V_{CC} = 12$ V
$V_{gen} = 2$ mV

Solution:

$V_{BB} = [R_2/(R_1 + R_2)]V_{CC}$
$V_{BB} = [2\text{ k}\Omega/(10\text{ k}\Omega + 2\text{ k}\Omega)]12\text{ V}$
$V_{BB} = 2$V

$V_E = V_{BB} - V_{BE}$
$V_E = 2\text{ V} - 0.7\text{ V}$
$V_E = 1.3$ V

$I_E = V_E/R_E$
$I_E = 1.3\text{ V}/2\text{ k}\Omega$
$I_E = 650\ \mu$A

$r'_e = (25\text{ mV})/I_E$
$r'_e = (25\text{ mV})/650\ \mu\text{A}$
$r'_e = 38.46\ \Omega$

$r_e = R_C \| R_L$
$r_e = 3.3\ k\Omega \| 10\ k\Omega$
$r_e = 2.48\ k\Omega$

$A_v = r_c / r_e'$
$A_v = 2.48\ k\Omega / 38.46\ \Omega$
$A_v = 64.4$

$Z_{in(Stage)} = R_E \parallel r_e'$
Since $R_E >> r_e'$
$Z_{in(Stage)} = r_e' = 38.5\ \Omega$

$v_{in} \approx (z_{in}(R_G + z_{in})V_{gen})$
$v_{in} = (38.5\ k\Omega\ (50\ \Omega + 38.5\ \Omega)\ 2\ mV)$
$v_{in} = 870\ \mu V$

$v_{out} = A_v(v_{in})$
$v_{out} = 64.4(870\ \mu V)$
$v_{out} = 56\ mV$

Answer: The output voltage is 56 mV.

11-27. *Given:*

$R_1 = 10\ k\Omega$
$R_2 = 2\ k\Omega$
$R_C = 3.3\ k\Omega$
$R_E = 2\ k\Omega$
$R_G = 50\ \Omega$
$V_{CC} = 15\ V$
$V_{gen} = 2\ mV$

Solution:

$V_{BB} = [R_2/(R_1 + R_2)]V_{CC}$
$V_{BB} = [2\ k\Omega/(10\ k\Omega + 2\ k\Omega)]15\ V$
$V_{BB} = 2.5\ V$

$V_E = V_{BB} - V_{BE}$
$V_E = 2.5\ V - 0.7\ V$
$V_E = 1.8\ V$

$I_E = V_E/R_E$
$I_E = 1.8\ V/2\ k\Omega$
$I_E = 900\ \mu A$

$r_e' = (25\ mV)/I_E$
$r_e' = (25\ mV)/900\ \mu A$
$r_e' = 27.8\ \Omega$

$r_c = R_C \| R_L$
$r_c = 3.3\ k\Omega \| 10\ k\Omega$
$r_c = 2.48\ k\Omega$

$A_v = r_c / r_e'$
$A_v = 2.48\ k\Omega/27.8\ \Omega$
$A_v = 89.3$

$Z_{in(Stage)} = R_E \parallel r_e'$
Since $R_E >> r_e'$
$Z_{in(Stage)} = r_e' = 27.8\ \Omega$

$v_{in} \approx (z_{in}(R_G + z_{in})V_{gen})$
$v_{in} = (27.8\ k\Omega\ (50\ \Omega + 27.8\ \Omega)2\ mV)$
$v_{in} = 715\ \mu V$

$v_{out} = A_v(v_{in})$
$v_{out} = 89.3(715\ \mu V)$
$v_{out} = 63.8\ mV$

Answer: The output voltage is 63.8 mV.

CRITICAL THINKING

11-28. *Given:*

$V_Z = 7.5\ V$
$V_{CC} = 15\ V$
$V_{out} = 6.8\ V$ (from Prob. 11-19)
$R_L = 33\ \Omega$

Solution:

$V_{CE} = V_{CC} - V_{out}$
$V_{CE} = 15\ V - 6.8\ V$
$V_{CE} = 8.2\ V$

$I_C = I_{out} = V_{out}/R_L$
$I_C = 6.8\ V/33\ \Omega$
$I_C = 206\ mA$

$P = V_{CE}I_C$
$P = (8.2\ V)(206\ mA)$
$P = 1.69\ W$

Answer: 1.69 W

11-29. *Given:*

$R_1 = 4.7\ k\Omega$
$R_2 = 2\ k\Omega$
$R_C = 1\ k\Omega$
$R_E = 1\ k\Omega$
$V_{CC} = 15V$
$\beta = 150$

Solution:

$V_{BB} = [R_2/(R_1 + R_2)]\ V_{CC}$ (Eq. 8-1)
$V_{BB} = [2\ k\Omega/(4.7\ k\Omega + 2\ k\Omega)]15\ V$
$V_{BB} = 4.48\ V$

$V_E = V_{BB} - V_{BE}$ (Eq. 8-2)
$V_E = 4.48\ V - 0.7\ V$
$V_E = 3.78\ V$

$I_E = V_E/R_E$ (Eq. 8-3)
$I_E = 3.78\ V/1\ k\Omega$
$I_E = 3.78\ mA$

$I_E = I_C$ (Eq. 8-4)

$V_C = V_{CC} - I_CR_C$ (Eq. 8-15)
$V_C = 15\ V - 3.78\ mA(1\ k\Omega)$
$V_C = 11.22\ V$

$I_B = I_C/\beta$ (Eq. 6-5)
$I_B = 3.78\ mA/150$
$I_B = 25.2\ \mu A$

Answer: The values are $V_B = 4.48\ V$, $V_E = 3.78\ V$, $V_C = 11.22\ V$, $I_E = 3.78\ mA$, $I_C = 3.78\ mA$, and $I_B = 25.2\ \mu A$.

11-30. *Given:*

$R_1 = 4.7\ k\Omega$
$R_2 = 2\ k\Omega$
$R_C = 1\ k\Omega$
$R_E = 1\ k\Omega$
$V_{CC} = 15\ V$
$\beta = 150$
$v_{in} = 5\ mV$
$v_{out(2)}$ is an emitter follower that has a gain of 1.

Solution:

$r_c = 1\ k\Omega$
$r_e = 1\ k\Omega$

$A_v = r_c/r_e$ (Eq. 10-7)
$A_v = 1\ k\Omega/1\ k\Omega$
$A_v = 1$

Answer: Both outputs are 5 mV; the top one is 180° out of phase. The purpose of this circuit is to produce two signals that are the same magnitude and 180° out of phase.

Trouble 7: Since there is voltage at *G* and none at *H,* the trouble is an open Q_2.

Chapter 12 Power Amplifiers

SELF-TEST

1. b	**10. d**	**19. a**	**28. a**
2. b	**11. c**	**20. c**	**29. d**
3. d	**12. d**	**21. b**	**30. d**
4. a	**13. b**	**22. d**	**31. b**
5. c	**14. b**	**23. a**	**32. c**
6. d	**15. b**	**24. a**	**33.d**
7. d	**16. b**	**25. b**	**34.c**
8. b	**17. c**	**26. c**	**35. a**
9. b	**18. a**	**27. c**	

JOB INTERVIEW QUESTIONS

6. Tuned RF amplifier. It would be impractical to use a class C amplifier for an audio application because it would distort the signal.

8. The lower the duty cycle is, the less the current drain.

11. Thermal conductive paste used to create a low thermal resistance path between the case and the heat sink.

12. Class A. No signal is lost in a class A amplifier: 360° in, 360° out. With class C, over half the signal is lost.

13. Narrowband.

PROBLEMS

12-1. *Given:*

$R_1 = 2$ kΩ
$R_2 = 470$ Ω
$R_C = 680$ Ω
$R_E = 220$ Ω
$R_L = 2.7$ kΩ
$V_{CC} = 15$V

Solution:

$R_C = 680$ Ω
$I_{C(\text{Sat})} = V_{CC}/(R_C + R_E)$ (Eq. 12-1)
$I_{C(\text{Sat})} = 15$ V/(680 Ω + 220 Ω)
$I_{C(\text{Sat})} = 16.67$ mA

Answer: The dc collector resistance 680 Ω, and the dc saturation current is 16.67 mA.

12-2. *Given:*

$R_1 = 2$ kΩ
$R_2 = 470$ Ω
$R_C = 680$ Ω
$R_E = 220$ Ω
$R_L = 2.7$ kΩ
$V_{CC} = 15$ V
$V_{BE} = 0.7$ V
$R_G = 50$ Ω

Solution:

$r_c = R_C \| R_L$ (Eq. 10-2)
$r_c = 680$ Ω‖2.7 kΩ
$r_c = 543$ Ω

$V_{BB} = [R_2/(R_1 + R_2)]V_{CC}$ (Eq. 8-1)
$V_{BB} = [470$ Ω/(2 kΩ + 470 Ω)]15 V
$V_{BB} = 2.85$ V

$V_E = V_{BB} - V_{BE}$ (Eq. 8-2)
$V_E = 2.85$ V – 0.7 V
$V_E = 2.15$ V

$I_E = I_{CQ} = V_E/R_E$ (Eq. 8-3)
$I_{CQ} = 2.15$ V/220 Ω
$I_{CQ} = 9.77$ mA

Since I_{CQ} is the center of the load line, the load line is linear, the other end is zero, and the ac saturation current is double the *Q* point current. The ac saturation current is 19.5 mA.

Answer: The ac collector resistance is 543 Ω, and the ac saturation current is 10.9 mA.

12-3. *Given:*

$R_1 = 2$ kΩ
$R_2 = 470$ Ω
$R_C = 680$ Ω
$R_E = 220$ Ω
$R_L = 2.7$ kΩ
$V_{CC} = 15$ V
$V_{BE} = 0.7$ V
$R_G = 50$ Ω
$r_c = 543$ Ω (from Prob. 12-2)
$I_{CQ} = 9.77$ mA (from Prob. 12-2)
$V_E = 2.15$ V (from Prob. 12-2)

Solution:

$V_C = V_{CC} - R_C I_{CQ}$
$V_C = 15$ V – (680 Ω)(9.77 mA)
$V_C = 8.36$ V

MP = $I_{CQ} r_c$ or V_{CEQ} (Eq. 12-8)
MP = (9.77 mA)(543 Ω)
MP = 5.31 V

or

$V_{CEQ} = V_C - V_E$
$V_{CEQ} = 8.36$ V – 2.15 V
$V_{CEQ} = 6.21$ V

MPP = 2MP
MPP = 2(5.31 V)
MPP = 10.62 V

Answer: The maximum peak-to-peak voltage is 10.62 V.

12-4. *Given:*

$R_1 = 4$ kΩ
$R_2 = 940$ Ω
$R_C = 1.36$ kΩ
$R_E = 440$ Ω
$R_L = 5.4$ kΩ
$V_{CC} = 15$V
$V_{BE} = 0.7$ V
$R_G = 100$ Ω

Solution:

$r_c = R_C \| R_L$ (Eq. 10-2)
$r_c = 1.36$ kΩ‖5.4 kΩ
$r_c = 1086$ Ω

Answer: The ac collector resistance is 1086 Ω.

12-5. *Given:*

$R_1 = 6$ kΩ
$R_2 = 1.41$ kΩ
$R_C = 2.04$ kΩ
$R_E = 660$ Ω
$R_L = 8.1$ kΩ
$V_{CC} = 15$V
$V_{BE} = 0.7$ V
$R_G = 150$ Ω

Solution:

$r_c = R_C \| R_L$ (Eq. 10-2)
$r_c = 2.04\ \text{k}\Omega \| 8.1\ \text{k}\Omega$
$r_c = 1.63\ \text{k}\Omega$

$V_{BB} = [R_2/(R_1 + R_2)]V_{CC}$ (Eq. 8-1)
$V_{BB} = [1.41\ \text{k}\Omega/(6\ \text{k}\Omega + 1.41\ \text{k}\Omega)]15\ \text{V}$
$V_{BB} = 2.85\ \text{V}$

$V_E = V_{BB} - V_{BE}$ (Eq. 8-2)
$V_E = 2.84\ \text{V} - 0.7\ \text{V}$
$V_E = 2.15\ \text{V}$

$I_E = I_{CQ} = V_E/R_E$ (Eq. 8-3)
$I_{CQ} = 2.15\ \text{V}/660\ \Omega$
$I_{CQ} = 3.26\ \text{mA}$

$V_C = V_{CC} - R_C I_{CQ}$
$V_C = 15\ \text{V} - (2.04\ \text{k}\Omega)(3.26\ \text{mA})$
$V_C = 8.35\ \text{V}$

$\text{MP} = I_{CQ} r_c$ or V_{CEQ} (Eq. 12-8)
$\text{MP} = (3.26\ \text{mA})(1.63\ \text{k}\Omega)$
$\text{MP} = 5.31\ \text{V}$

or

$V_{CEQ} = V_C - V_E$
$V_{CEQ} = 8.35\ \text{V} - 2.15\ \text{V}$
$V_{CEQ} = 6.2\ \text{V}$

$\text{MPP} = 2\text{MP}$
$\text{MPP} = 2(5.31\ \text{V})$
$\text{MPP} = 10.62\ \text{V}$

Answer: The maximum peak-to-peak voltage is 10.62 V.

12-6. *Given:*

$R_1 = 200\ \Omega$
$R_2 = 100\ \Omega$
$R_C = 100\ \Omega$
$R_E = 68\ \Omega$
$R_L = 100\ \Omega$
$V_{CC} = 30\ \text{V}$

Solution:

$R_C = 100\ \Omega$
$I_{C(\text{Sat})} = V_{CC}/R_C + R_E$
$I_{C(\text{Sat})} = 30\ \text{V}/100\ \Omega + 68\ \Omega$
$I_{C(\text{Sat})} = 179\ \text{mA}$

Answer: The dc collector resistance is 100 Ω, and the saturation current is 179 mA.

12-7. *Given:*

$R_1 = 200\ \Omega$
$R_2 = 100\ \Omega$
$R_C = 100\ \Omega$
$R_E = 68\ \Omega$
$R_L = 100\ \Omega$
$V_{CC} = 30\ \text{V}$
$V_{BE} = 0.7\ \text{V}$

Solution:

$r_c = R_C \| R_L$
$r_c = 100\ \Omega \| 100\ \Omega$
$r_c = 50\ \Omega$

$V_{BB} = [R_2/(R_1 + R_2)]V_{CC}$
$V_{BB} = [100\ \Omega/(200\ \Omega + 100\ \Omega)]30\ \text{V}$
$V_{BB} = 10\ \text{V}$

$V_E = V_{BB} - V_{BE}$
$V_E = 10\ \text{V} - 0.7\ \text{V}$
$V_E = 9.3\ \text{V}$

$I_E = I_{CQ} = V_E/R_E$
$I_{CQ} = 9.3\ \text{V}/68\ \Omega$
$I_{CQ} = 137\ \text{mA}$

$I_{c(\text{Sat})} = 2(I_{CQ})$
$I_{c(\text{Sat})} = 2(137\ \text{mA})$
$I_{c(\text{Sat})} = 274\ \text{mA}$

Answer: The ac collector resistance is 50 Ω, and the ac saturation current is 274 mA.

12-8. *Given:*

$R_1 = 200\ \Omega$
$R_2 = 100\ \Omega$
$R_C = 100\ \Omega$
$R_E = 68\ \Omega$
$R_L = 100\ \Omega$
$V_{CC} = 30\ \text{V}$
$V_{BE} = 0.7\ \text{V}$
$r_c = 50\ \Omega$ (from Prob. 12-7)
$I_{CQ} = 137\ \text{mA}$ (from Prob. 12-7)
$i_{c(\text{Sat})} = 174\ \text{mA}$ (from Prob. 12-7)
$V_E = 9.3\ \text{V}$ (from Prob. 12-7)

Solution:

$V_C = V_{CC} - R_C I_{CQ}$
$V_C = 30\ \text{V} - (100\ \Omega)(137\ \text{mA})$
$V_C = 16.3\ \text{V}$
$V_{CEQ} = V_C - V_E$
$V_{CEQ} = 16.3\text{V} - 9.3\text{V}$
$V_{CEQ} = 7\ \text{V}$

$\text{MP} = V_{CEQ} = 7\ \text{V}$
$\text{MPP} = 2\text{MP} = 14\ \text{V}$

or

$\text{MP} = I_{CQ} r_c$
$\text{MP} = (137\ \text{mA})(50\ \Omega)$
$\text{MP} = 6.85\ \text{V}$
$\text{MPP} = 2\text{MP} = 13.7\ \text{V}$

Answer: The maximum peak-to-peak voltage is 13.7 V.

12-9. *Given:*

$R_1 = 400\ \Omega$
$R_2 = 200\ \Omega$
$R_C = 200\ \Omega$
$R_E = 136\ \Omega$
$R_L = 200\ \Omega$
$V_{CC} = 30\ \text{V}$
$V_{BE} = 0.7\ \text{V}$

Solution:

$r_c = R_C \| R_L$
$r_c = 200\ \Omega \| 200\ \Omega$
$r_c = 100\ \Omega$

Answer: The ac collector resistance is 100 Ω.

12-10. *Given:*

$R_1 = 600\ \Omega$
$R_2 = 300\ \Omega$
$R_C = 300\ \Omega$
$R_E = 204\ \Omega$
$R_L = 300\ \Omega$
$V_{CC} = 30\ \text{V}$
$V_{BE} = 0.7\ \text{V}$

Solution:

$V_{BB} = [R_2/(R_1 + R_2)]V_{CC}$

V_{BB} = [300 Ω/(600 Ω + 300 Ω)]30 V
V_{BB} = 10 V

$V_E = V_{BB} - V_{BE}$
V_E = 10 V – 0.7 V
V_E = 9.3 V

$I_E = I_{CQ} = V_E/R_E$
I_{CQ} = 9.3 V/204 Ω
I_{CQ} = 45.59 mA

$V_C = V_{CC} - R_C I_{CQ}$
V_C = 30 V – (300 Ω)(45.59 mA)
V_C = 16.3 V

$V_{CEQ} = V_C - V_E$
V_{CEQ} = 16.3 V – 9.3 V
V_{CEQ} = 7 V

MP = V_{CEQ} = 7 V
MPP = 2MP = 14 V

or

MP = $I_{CQ} r_c$
MP = (45.59 mA) (150 Ω)
MP = 6.85 V
MPP = 2MP = 13.7 V

Answer: The maximum peak-to-peak voltage is 13.7 V.

12-11. *Given:*

P_{out} = 2 W
P_{in} = 4 mW

Solution:

$A_P = P_{out}/P_{in}$ (Eq. 12-12)
A_P = 2 W/4 mW
A_P = 500

Answer: The power gain is 500.

12-12. *Given:*

V_{out} = 15 V pp
R_L = 1 kΩ
P_{in} = 400 μW

Solution:

$P_{out} = V^2/8R$
$P_{out} = (15\ V)^2/8$ kΩ
P_{out} = 28.1 mW

$A_P = P_{out}/P_{in}$ (Eq. 12-12)
A_P = 28.1 mW/400 μW
A_P = 70.3

Answer: The power gain is 70.3.

12-13. *Given:*

R_1 = 2 kΩ
R_2 = 470 Ω
R_C = 680 Ω
R_E = 220 Ω
R_L = 2.7 kΩ
V_{CC} = 15 V
V_{BE} = 0.7 V
R_G = 50 Ω
V_{BB} = 2.85 V (from Prob. 12-2)

Solution:

$I_{bias} = V_{CC}/(R_1 + R_2)$
I_{bias} = 15 V/(2 kΩ + 470 Ω)
I_{bias} = 6.07 mA

$V_E = V_{BB} - V_{BE}$ (Eq. 8-2)
V_E = 2.85 V – 0.7 V
V_E = 2.15 V

$I_E = V_E/R_E$ (Eq. 8-3)
I_E = 2.15 V/220 Ω
I_E = 9.77 mA

$I_{dc} = I_{bias} + I_E$
I_{dc} = 6.07 mA + 9 77 mA
I_{dc} = 15.84 mA

Answer: The current drain is 15.84 mA.

12-14. *Given:*

I_{dc} = 15.84 mA (from Prob. 12-13)
V_{CC} = 15 V

Solution:

$P_{dc} = I_{dc} V_{CC}$ (Eq. 12-17)
P_{dc} = (15.84 mA)(15 V)
P_{dc} = 237.6 mW

Answer: The dc input power is 237.6 mW.

12-15. *Given:*

MPP = 10.62 V (from Prob. 12-3)
R_L = 2.7 kΩ
P_{dc} = 237.6 mW (from Prob. 12-14)

Solution:

$P_{out(max)} = MPP^2/8R_L$ (Eq. 12-15)
$P_{out} = (10.62\ V)^2/8(2.7$ kΩ)
P_{out} = 5.22 mW

η = $[P_{out}/P_{in}]$100%
η = [5.22 mW/237.6 mW]100%
η = 2.2%

Answer: The efficiency is 2.2%.

12-16. *Given:*

I_{CQ} = 9.77 mA (from Prob. 12-2)
V_{CEQ} = 6.21 V (from Prob. 12-3)

Solution:

$P_{DQ} = V_{CEQ} I_{CQ}$ (Eq. 12-16)
P_{DQ} = (6.21 V)(9.77 mA)
P_{DQ} = 60.7 mW

Answer: The quiescent power dissipation is 60.7 mW.

12-17. *Given:*

R_1 = 200 Ω
R_2 = 100 Ω
R_C = 100 Ω
R_E = 68 Ω
R_L = 100 Ω
V_{CC} = 30 V
V_{BE} = 0.7 V
V_{BB} = 10 V (from Prob. 12-7)

Solution:

$I_{bias} = V_{CC}/(R_1 + R_2)$
I_{bias} = 30 V/(200 Ω + 100 Ω)
I_{bias} = 100 mA

$V_E = V_{BB} - V_{BE}$
V_E = 10 V – 0.7 V
V_E = 9.3 V

$I_E = V_E/R_E$
I_E = 9.3 V/68 Ω
I_E = 136.8 mA ≈ 137 mA

$I_{dc} = I_{bias} + I_E$
$I_{dc} = 100\text{ mA} + 137\text{ mA}$
$I_{dc} = 237\text{ mA}$

Answer: The current drain is 237 mA.

12-18. *Given:*

$I_{dc} = 2.37\text{ mA}$ (from Prob. 12-17)
$V_{CC} = 30\text{V}$

Solution:

$P_{dc} = I_{dc}V_{CC}$
$P_{dc} = (237\text{ mA})(30\text{ V})$
$P_{dc} = 7.11\text{ W}$

Answer: The dc input power is 7.11 W.

12-19. *Given:*

MPP = 2MP = 13.7 V (from Prob. 12-10)
$P_{dc} = 7.11\text{ W}$ (from Prob. 12-18)
$R_L = 100\ \Omega$

Solution:

$P_{out(max)} = \text{MPP}^2/8R_L$
$P_{out} = (13.7\text{ V})^2/8(100\ \Omega)$
$P_{out} = 235\text{ mW}$

$\eta = [P_{out}/P_{in}]100\%$
$\eta = [235\text{ mW}/7.11\text{ W}]100\%$
$\eta = 3.3\%$

Answer: The efficiency is 3.3%.

12-20. *Given:*

$I_{CQ} = 137\text{ mA}$ (from Prob. 12-7)
$V_{CEQ} = 7\text{ V}$ (from Prob. 12-8)

Solution:

$P_{DQ} = V_{CEQ}I_{CQ}$
$P_{DQ} = (7\text{ V})(137\text{ mA})$
$P_{DQ} = 960\text{ mW}$

Answer: The quiescent power dissipation is 960 mW.

12-21. *Given:*

$R_1 = 10\ \Omega$
$R_2 = 2.2\ \Omega$
$R_E = 1\ \Omega$
$V_{CC} = 10\text{ V}$
$V_{BE} = 0.7\text{ V}$

Solution:

$V_{BB} = [R_2/(R_1 + R_2)]V_{CC}$ (Eq. 8-1)
$V_{BB} = [2.2\ \Omega/(10\ \Omega + 2.2\ \Omega)]10\text{ V}$
$V_{BB} = 1.80\text{ V}$

$V_E = V_{BB} - V_{BE}$ (Eq. 8-2)
$V_E = 1.80\text{ V} - 0.7\text{ V}$
$V_E = 1.10\text{ V}$

$I_E = V_E/R_E$ (Eq. 8-3)
$I_E = 1.1\text{ V}/1\ \Omega$
$I_E = 1.1\text{ A}$

Answer: The dc emitter current is 1.1 A.

12-22. *Given:*

$R_1 = 10\ \Omega$
$R_2 = 2.2\ \Omega$
$R_E = 1\ \Omega$
$V_{CC} = 10\text{ V}$
$V_{BE} = 0.7\text{ V}$
$R_C = 3.2\ \Omega$
$V_{out} = 5\text{ V pp}$

Solution:

$P_{out} = v_{out}^2/8RL$ (Eq. 12-15)
$P_{out} = (5\text{ V})^2/8(3.2\ \Omega)$
$P_{out} = 0.977\text{ W}$

$I_{bias} = V_{CC}/(R_1 + R_2)$
$I_{bias} = 10\text{ V}/(10\ \Omega + 2.2\ \Omega)$
$I_{bias} = 0.82\text{ A}$

$V_{BB} = [R_2/(R_1 + R_2)]V_{CC}$ (Eq. 8-1)
$V_{BB} = [2.2\ \Omega/(10\ \Omega + 3.2\ \Omega)]\ 10\text{ V}$
$V_{BB} = 1.80\text{ V}$

$V_E = V_{BB} - V_{BE}$ (Eq. 8-2)
$V_E = 1.80\text{ V} - 0.7\text{ V}$
$V_E = 1.10\text{ V}$

$I_E = V_E/R_E$ (Eq. 8-3)
$I_E = 1.10\text{ V}/1\ \Omega$
$I_E = 1.1\text{ A}$

$I_{dc} = I_{bias} + I_E$
$I_{dc} = 0.82\text{ A} + 1.1\text{ A}$
$I_{dc} = 1.92\text{ A}$

$P_{dc} = I_{dc}V_{CC}$ (Eq. 12-17)
$P_{dc} = (1.92\text{ A})(10\text{ V})$
$P_{dc} = 19.2\text{ W}$

$\eta = [P_{out}/P_{in}]100\%$
$\eta = [0.977\text{ W}/19.2\text{ W}]100\%$
$\eta = 5.1\%$

Answer: The output power is 0.977 W, and the efficiency is 5.1%.

12-23. *Given:*

$V_{cut\text{-}off} = 12\text{ V}$

Solution:

$\text{MPP} = 12\ V_{cut\text{-}off}$
$\text{MPP} = 2(12\text{ V})$
$\text{MPP} = 24\text{ V}$

Answer: The maximum peak-to-peak voltage is 24 V.

12-24. *Given:*

$V_{CC} = \text{MPP} = 30\text{ V}$
$R_L = 16\ \Omega$

Solution:

$P_{D(max)} = \text{MPP}^2/40R_L$
$P_{D(max)} = (30\text{ V})^2/40(16\ \Omega)$
$P_{D(max)} = 1.41\text{ W}$

Answer: The maximum power dissipation of each transistor is 1.41 W.

12-25. *Given:*

$V_{CC} = \text{MPP} = 30\text{ V}$
$R_L = 16\ \Omega$

Solution:

$P_{out(max)} = \text{MPP}^2/8R_L$
$P_{out(max)} = (30\text{ V})^2/8(16\ \Omega)$
$P_{out(max)} = 7.03\text{ W}$

Answer: The maximum output power is 7.03 W.

12-26. *Given:*

$R_1 = 100\ \Omega$
$R_2 = 100\ \Omega$
$R_L = 50\ \Omega$
$V_{CC} = 30\text{ V}$
$V_{Diode} = 0.7\text{ V}$

Solution:

$I_{\text{bias}} = (V_{CC} - 2V_{\text{Diode}})/(R_1 + R_2)$
$I_{\text{bias}} = 28.6\text{ V}/(100\ \Omega + 100\ \Omega)$
$I_{\text{bias}} = 143\text{ mA}$

$I_{CEQ} \approx I_{\text{bias}} = 143\text{ mA}$

Answer: The quiescent collector current is 143 mA.

12-27. *Given:*

$V_{CC} = \text{MPP} = 30\text{ V}$
$R_L = 50\ \Omega$

Solution:

$I_{\text{bias}} = (V_{CC} - 2V_{\text{Diode}})/(R_1 + R_2)$
$I_{\text{bias}} = 28.6\text{ V}/(100\ \Omega + 100\ \Omega)$
$I_{\text{bias}} = 143\text{ mA}$

$I_{\text{dc}} = 238\text{ mA}$

$P_{\text{dc}} = I_{\text{dc}}V_{CC}$
$P_{\text{dc}} = 238\text{ mA}(30\text{ V})$
$P_{\text{dc}} = 7.14\text{ W}$

$P_{\text{out(max)}} = \text{MPP}^2/8R_L$
$P_{\text{out(max)}} = (30\text{ V})^2/8(50\ \Omega)$
$P_{\text{out(max)}} = 2.25\text{ W}$

$\eta = [\text{P}_{\text{out}}/\text{P}_{\text{in}}]100\%$
$\eta = [2.25\text{ W}/750\text{ mW}]100\%$
$\eta = 31.5\%$

Answer: The efficiency is 31.5%.

12-28. *Given:*

$V_{CC} = \text{MPP} = 30\text{ V}$
$R_L = 50\ \Omega$

Solution:

$I_{\text{bias}} = (V_{CC} - 2V_{\text{Diode}})/(R_1 + R_2)$
$I_{\text{bias}} = 28.6\text{ V}/(1\text{ k}\Omega + 1\text{ k}\Omega)$
$I_{\text{bias}} = I_{CQ} = 14.3\text{ mA}$

$I_{\text{dc}} = 110\text{ mA}$

$P_{\text{dc}} = I_{\text{dc}}V_{CC}$
$P_{\text{dc}} = 110\text{ mA}(30\text{ V})$
$P_{\text{dc}} = 3.3\text{ W}$

$P_{\text{out(max)}} = \text{MPP}^2/8R_L$
$P_{\text{out(max)}} = (30\text{ V})^2/8(50\ \Omega)$
$P_{\text{out(max)}} = 2.25\text{ W}$

$\eta = [P_{\text{out}}/\text{P}_{\text{in}}]100\%$
$\eta = [2.25\text{ W}/3.3\text{ W}]100\%$
$\eta = 68.3\%$

Answer: The efficiency is 68.3% and the quiescent collector current is 14.3 mA.

12-29. *Given:*

$\text{MPP} = 30\text{ V}$
$R_L = 100\ \Omega$

Solution:

$P_{\text{out(max)}} = \text{MPP}^2/8R_{\text{L}}$
$P_{\text{out(max)}} = (30\text{ V})^2/8(100\ \Omega)$
$P_{\text{out(max)}} = 1.13\text{ W}$

Answer: The maximum power output is 1.13 W.

12-30. *Given for 1st stage:*

$R_1 = 10\text{ k}\Omega$
$R_2 = 5.6\text{ k}\Omega$
$R_C = 1\text{ k}\Omega$
$R_E = 1\text{ k}\Omega$
$V_{BB} = 10.7\text{ V}$
$V_E = 10\text{ V}$

Second Stage:

$R_1 = 12\text{ k}\Omega$
$R_2 = 1\text{ k}\Omega$
$R_E = 100\text{ k}\Omega$
$\beta = 200$
$V_{CC} = 30\text{ V}$

Solution:

$r'_e = 25\text{ mV}/I_E$
$r'_e = 25\text{ mV}/(10\text{ V}/1\text{ k}\Omega)$
$r'_e = 2.5\ \Omega$

$r_e = R_E$ (second stage)
$r_e = 100\ \Omega$

$r_c = R_C \| Z_{\text{in(Stage 2)}}$
$Z_{\text{in(Stage 2)}} = 12\text{ k}\Omega \| 910\ \Omega \| \beta\, r'_e$
$r_c = 1\text{ k}\Omega \| 12\text{ k}\Omega \| 910\ \Omega \| 200(100\ \Omega)$
$r_c = 496\ \Omega$

$A_{\text{v(Stage 1)}} = r_c / r'_e$
$A_{\text{v(Stage 1)}} = 496\ \Omega/2.5\ \Omega$
$A_{\text{v(Stage 1)}} = 188$

Answer: The voltage gain of the first stage is 188.

12-31. *Given for 2nd Stage:*

$R_1 = 12\text{ k}\Omega$
$R_2 = 1\text{ k}\Omega$
$R_E = 100\ \Omega$
$R_C = 1\text{ k}\Omega$
$V_E = 1.43\text{ V}$

3rd Stage:

$\beta = 200$
$V_{CC} = 30\text{ V}$
$R_E = 100\ \Omega$

Solution:

$I_E = V_E/R_E$ (Eq. 8-3)
$I_E = 1.43\text{ V}/100\ \Omega$
$I_E = 14.3\text{ mA}$

$r'_e = 25\text{ mV}/I_E$ (Eq. 9-10)
$r'_e = 25\text{ mV}/(14.3\text{ mA})$
$r'_e = 1.75\ \Omega$

$r_e = R_E$ (second stage)
$r_e = 100\ \Omega$
$Z_{\text{in(base)}} = \beta\, r'_e$ (Eq. 10-9)
$Z_{\text{in(base)}} = 200(100\Omega)$
$Z_{\text{in(base)}} = 20\text{ k}\Omega$

$r_c = R_C \| Z_{\text{in(base)}}$
$r_c = 1\text{ k}\Omega \| 20\text{ k}\Omega$
$r_c = 952\ \Omega$

$A_{\text{v}} = r_c/(r_e + r'_e)$
$A_{\text{v}} = 952\ \Omega/(100\ \Omega + 1.75\ \Omega)$
$A_{\text{v}} = 9.36$

Answer: The gain of the second stage is 9.36.

12-32. *Given:*

$I_E = 14.3\text{ mA}$

Solution:

$I_{CQ} = I_{\text{bias}} = 14.3\text{ mA}$

Answer: The quiescent collector current is 14.3 mA.

12-33. *Given:*

$A_{\text{v1}} = 188$ (from Prob. 12-30)
$A_{\text{v2}} = 9.36$ (from Prob. 12-31)

Solution:

$A_{v3} = 1$ (Eq. 12-25)
$A_v = A_{v1}A_{v2}A_{v3}$
$A_v = (188)(9.36)(1)$
$A_v = 1679$

Answer: The total voltage gain is 1679.

12-34. *Given:* $v_{in} = 5\ V_{rms.}$

Solution:

$Vpp = 2.828\ V_{rms.}$
$Vpp = 2.828(5\ V)$
$Vpp = 14.14$ V pp

Since the input is clamped at 0.7 V, the negative peak is –13.44 V. The average value is –6.37 V, so the voltmeter will read –6.37 V.

Answer: The input voltage is 14.14 V pp, and the base voltage is –6.37 V.

12-35. *Given:*

$L = 1\ \mu H$
$C = 220$ pF

Solution:

$f_r = 1/(2\pi\sqrt{LC})$ (Eq. 12-29)
$f_r = 1/[2\pi\sqrt{(1\mu H)(220 pF)}]$
$f_r = 10.73$ MHz

Answer: The resonant frequency is 10.73 MHz.

12-36. *Given:*

$L = 2\ \mu H$
$C = 220$ pF

Solution:

$f_r = 1/(2\pi\sqrt{LC})$ (Eq. 12-29)
$f_r = 1/[2\pi\sqrt{(2\mu H)(220\ pF)}]$
$f_r = 7.59$ MHz

Answer: The resonant frequency is 7.59 MHz.

12-37. *Given:*

$L = 1\ \mu H$
$C = 100$ pF

Solution:

$f_r = 1/(2\pi\sqrt{LC})$ (Eq. 12-29)
$f_r = 1/[2\pi\sqrt{(1\mu H)(100 pF)}]$
$f_r = 15.92$ MHz

Answer: The resonant frequency is 15.92 MHz.

12-38. *Given:*

$P_{out} = 11$ mW
$P_{in} = 50\ \mu W$

Solution:

$Ap = P_{out}/P_{in}$ (Eq. 12-12)
$Ap = 11\ mW/50\ \mu W$
$Ap = 220$

Answer: The power gain is 220.

12-39. *Given:*

$v_{out} = 50$ V pp
$R_L = 10\ k\Omega$

Solution:

$P_{out} = v_{out}^2/8R_L$ (Eq. 12-14)
$P_{out} = (50\ V\ pp)^2/8(10\ k\Omega)$
$P_{out} = 31.25$ mW

Answer: The output power is 31.25 mW.

12-40. *Given:* $V_{CC} = 30$ V.

Solution:

$MPP = 2\ V_{CC}$ (Eq. 12-38)
$MPP = 2(30\ V)$
$MPP = 60$ V

$P_{out} = MPP^2/8R_L$ (Eq. 12-15)
$P_{out} = (60\ V\ pp)^2/8(10\ k\Omega)$
$P_{out} = 45$ mW

Answer: The maximum output power is 45 mW.

12-41. *Given:*

$I_{dc} = 0.5$ mA
$V_{CC} = 30$ V

Solution:

$P_{dc} = V_{CC}I_{dc}$ (Eq. 12-17)
$P_{dc} = (30\ V)(0.5\ mA)$
$P_{dc} = 15$ mW

Answer: The dc input power is 15 mW.

12-42. *Given:*

$I_{dc} = 0.4$ mA
$V_{CC} = 30$ V
$v_{out} = 30$ V pp
$R_L = 10\ k\Omega$

Solution:

$P_{dc} = V_{CC}I_{dc}$ (Eq. 12-17)
$P_{dc} = (30\ V)(0.4\ mA)$
$P_{dc} = 12$ mW

$P_{out} = v_{out}^2/8R_L$ (Eq. 12-14)
$P_{out} = (30\ V\ pp)^2/8(10\ k\Omega)$
$P_{out} = 11.25$ mW

$\eta = (P_{out}/P_{in})100\%$ (Eq. 12-18)
$\eta = (11.25\ mW/12\ mW)100\%$
$\eta = 93.75\%$

Answer: The efficiency is 93.75%.

12-43. *Given:*

$Q = 125$
$f_r = 10.73$ MHz (from Prob. 12-35)

Solution:

$B = f_r/Q$
$B = 10.73\ MHz/125$
$B = 85.84$ kHz

Answer: The bandwidth is 85.84 kHz.

12-44. *Given:*

$Q = 125$
$f_r = 10.73$ MHz (from Prob. 12-35)
$R_L = 10\ k\Omega$
MPP = 60 V (from Prob. 12-40)
$L = 1\ \mu H$

Solution:

$X_L = 2\pi fL$
$X_L = 2(3.14)(10.73\ MHz)(1\ \mu H)$
$X_L = 67.38\ \Omega$

$R_P = QX_L$ (Eq. 12-33)
$R_P = (125)(67.38\ \Omega)$
$R_P = 8.42\ k\Omega$

$r_C = R_P \| R_L$ (Eq. 12-34)

$r_C = 8.42\ \text{k}\Omega \| 10\ \text{k}\Omega$
$r_C = 4.57\ \text{k}\Omega$

$P_D = \text{MPP}^2/40r_C$ (Eq. 12-39)
$P_D = (60\ \text{V})^2/40(4.57\ \text{k}\Omega)$
$P_D = 19.7\ \text{mW}$

Answer: The worst-case power dissipation is 19.7 mW.

12-45. *Given:*

$P_D = 625\ \text{mW}$
$D = 5\ \text{mW/°C}$
$T_A = 100°\text{C}$

Solution:

$\Delta P = D(T_A - 25°\text{C})$ (Eq. 12-40)
$\Delta P = (5\ \text{mW/°C})(100°\text{C} - 25°\text{C})$
$\Delta P = 375\ \text{mW}$

$P_{D(\max)} = P_D - \Delta P$
$P_{D(\max)} = 625\ \text{mW} - 375\ \text{mW}$
$P_{D(\max)} = 250\ \text{mW}$

Answer: The worst-case power rating is 250 mW.

12-46. *Given:* Derating curve on Fig. 12-36.

Answer: The maximum dissipation at 100°C is 2 W.

12-47. *Given:*

$P_D = 115\ \text{W}$
$D = 0.657\ \text{W/°C}$
$T_C = 90°\text{C}$

Solution:

$\Delta P = D(T_C - 25°\text{C})$ (Eq. 12-40)
$\Delta P = (0.657\ \text{W/°C})(90°\text{C} - 25°\text{C})$
$\Delta P = 42.7\ \text{W}$

$P_{D(\max)} = P_D - \Delta P$
$P_{D(\max)} = 115\ \text{W} - 42.7\ \text{W}$
$P_{D(\max)} = 72.3\ \text{W}$

Answer: The power rating is 72.3 W with a case temperature of 90°C.

CRITICAL THINKING

12-48. *Answer:* The input is larger than the maximum allowed input for an undistorted output. The input is driving the output into saturation, clipping the wave off, and turning it into a square wave.

12-49. *Answer:* Electrically, it would be safe to touch, but it may be hot and cause a burn.

12-50. *Answer:* No, the maximum efficiency of anything is 100 percent. It is impossible to get more power out of a device than is put into the device.

12-51. *Answer:* No, the ac load line is more vertical because the ac collector resistance is usually less than the dc collector resistance. If the collector had an inductor instead of a resistor, the ac resistance would be greater than the dc resistance and make the ac load line less vertical.

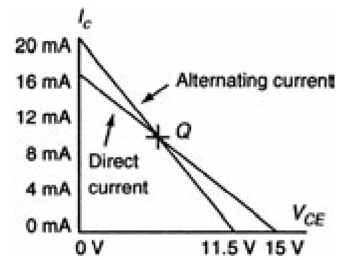
12-52. *Given:*

$I_{C(\text{Sat})} = 16.67\ \text{mA}$ (from Prob. 12-1)
$V_{CC} = 15\ \text{V}$
$I_{CQ} = 9.77\ \text{mA}$ (from Prob. 12-2)
$\text{MP} = I_{CQ}\, r_c = 5.31\ \text{V}$ (from Prob. 12-3)
$V_{CEQ} = 6.21\ \text{V}$ (from Prob. 12-3)

Solution:

The left side of the dc load line is $I_{C(\text{Sat})}$, and the right side is V_{CC}. The Q point is I_{CQ}, V_{CEQ}. The ac load line passes through the Q point. The right side of the ac load line is $I_{CQ}\, r_c$ above the Q point, or 11.52 V. This gives the line a slope of $I_{CQ}/I_{CQ}\, r_c = 9.77\ \text{mA}/5.31\ \text{V} = 1.84\ \text{mA/V}$. To find the ac saturation current, take the ac voltage maximum multiplied by the slope = (11.52 V)(1.84 mA/V) = 21.2 mA.

Answer: See the graph.



12-53. *Answer:*

P_L: The power across the load resistor should increase because the emitter current is increased, the gain is slightly increased, and the output voltage and the output power will increase.

P_D: Since MPP is reduced, the P_D is also reduced ($P_D = \text{MPP}^2/40r_c$).

P_S: A higher V_{CC} will cause the input power to increase ($P = V^2/R$).

MPP: A higher V_{CC} will cause the emitter voltage to increase and thus the emitter current to increase. This causes an increase in the collector resistor voltage drop, which reduces V_{CEQ} and, in turn, the MPP.

η: Since the dc input power is increased and the output power is increased, the efficiency remains constant.

12-54. *Answer:*

P_L: The power across the load resistor should decrease because the emitter current is decreased, the gain is slightly decreased, and the output voltage and the output power will increase.

P_D: Since MPP is increased, the P_D is also increased ($P_D = \text{MPP}^2/40r_c$).

P_S: A higher R_1 will cause the input power to decrease ($P = V^2/R$).

MPP: A higher R_1 will cause the emitter voltage to decrease and thus the emitter current to decrease. This causes a decrease in the collector resistor voltage drop, which will increase V_{CEQ} and, in turn, increase the MPP.

η: Since the dc input power is decreased and the output power is decreased, the efficiency is not changed.

12-55. *Answer:*

P_L: The power across the load resistor should increase because the emitter current is increased, the gain is slightly increased, and the output voltage and the output power will increase.

P_D: Since MPP is reduced, the P_D is also reduced ($P_D = \text{MPP}^2/40r_c$).

P_S: A higher R_2 will cause the input power to decrease ($P = V^2/R$).

Solution:

$V_{GS(\text{off})} = -V_P$ (Eq. 13-2)
$V_P = 6$ V

$R_{DS} = V_P/I_{DSS}$ (Eq. 13-1)
$R_{DS} = 6$ V/30 mA
$R_{DS} = 200\ \Omega$

$V_D = [R_{DS}/(R_{DS} + R_D)]V_{DD}$
$V_D = [200\ \Omega/(200\ \Omega + 20\ \text{k}\Omega)]20$ V
$V_D = 0.198$ V

Answer: The drain voltage is 0.198 V.

13-12. *Given:*

$V_{DD} = 20$ V
$R_D = 10\ \text{k}\Omega$
$V_{GS(\text{off})} = -6$ V
$I_{DSS} = 30$ mA

Solution:

$I_{D(\text{Sat})} = V_{DD}/R_D$
$I_{D(\text{Sat})} = 20\ \text{V}/10\ \text{k}\Omega$
$I_{D(\text{Sat})} = 2$ mA

$V_{GS(\text{off})} = V_P$. (Eq. 13-2)
$V_P = 6$ V

$R_{DS} = V_P/I_{DSS}$ (Eq. 13-1)
$R_{DS} = 6$ V/30 mA
$R_{DS} = 200\ \Omega$

$V_D = [R_{DS}/(R_{DS} + R_D)]V_{DD}$
$V_D = [200\ \Omega/(200\ \Omega + 10\ \text{k}\Omega)]20$ V
$V_D = 0.392$ V

Answer: The drain saturation current is 2 mA, and the drain voltage is 0.392 V.

13-13. *Given:*

$R_1 = 1.5\ \text{M}\Omega$
$R_2 = 1\ \text{M}\Omega$
$R_S = 22\ \text{k}\Omega$
$R_D = 10\ \text{k}\Omega$
$V_{DD} = 25$ V

Solution:

$V_G = [R_2/(R_1 + R_2)]V_{DD}$
$V_G = [1\ \text{M}\Omega/(1.5\ \text{M}\Omega + 1\ \text{M}\Omega)]\ 25$ V
$V_G = 10$ V

$I_D = V_G/R_S$ (Eq. 13-10)
$I_D = 10\ \text{V}/22\ \text{k}\Omega$
$I_D = 0.455$ mA

$V_D = V_{DD} - I_DR_D$ (Eq. 13-4)
$V_D = 25\ \text{V} - (0.455\ \text{mA})(10\ \text{k}\Omega)$
$V_D = 20.45$ V

Answer: The drain voltage is 20.45 V.

13-14. *Given:*

$R_1 = 1.5\ \text{M}\Omega$
$R_2 = 1\ \text{M}\Omega$
$R_S = 22\ \text{k}\Omega$
$R_D = 10\ \text{k}\Omega$
$V_{DD} = 25$ V
$V_G = 10$ V (from Prob. 13-13)

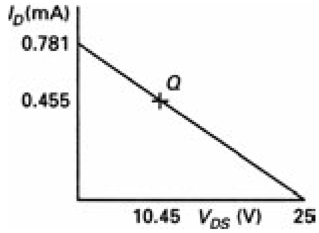
$I_D = 0.455$ mA (from Prob. 13-13)
$V_D = 20.45$ V (from Prob. 13-13)

Solution:

$I_{D(\text{Sat})} = V_{DD}/(R_D + R_S)$
$I_{D(\text{Sat})} = 25\ \text{V}/(10\ \text{k}\Omega + 22\ \text{k}\Omega)$
$I_{D(\text{Sat})} = 0.781$ mA

$V_S \approx V_G$

$V_{DSQ} = V_D - V_S$
$V_{DSQ} = 20.45\ \text{V} - 10$ V
$V_{DSQ} = 10.45$ V



DC load line and *Q* point for Prob. 13-14.

13-15. *Given:*

$V_{DD} = 25$ V
$V_{SS} = -25$ V
$R_D = 7.5\ \text{k}\Omega$
$R_S = 18\ \text{k}\Omega$

Solution:

$I_D = V_{SS}/R_S$ (Eq. 13-12)
$I_D = -25\ \text{V}/18\ \text{k}\Omega$
$I_D = 1.39$ mA

$V_D = V_{DD} - I_DR_D$ (Eq. 13-4)
$V_D = 25\ \text{V} - (1.39\ \text{mA})(7.5\ \text{k}\Omega)$
$V_D = 14.58$ V

Answer: The drain voltage is 14.58 V.

13-16. *Given:*

$V_{DD} = 25$ V
$V_{SS} = -25$ V
$R_D = 7.5\ \text{k}\Omega$
$R_S = 30\ \text{k}\Omega$

Solution:

$I_D = V_{SS}/R_S$ (Eq. 13-12)
$I_D = -25\ \text{V}/30\ \text{k}\Omega$
$I_D = 0.833$ mA

$V_D = V_{DD} - I_DR_D$ (Eq. 13-4)
$V_D = 25\ \text{V} - (0.833\ \text{mA})(7.5\ \text{k}\Omega)$
$V_D = 18.75$ V

Answer: The drain voltage is 18.75 V.

13-17. *Given:*

$V_{DD} = 15$ V
$V_{EE} = -9$ V
$R_D = 7.5\ \text{k}\Omega$
$R_E = 8.2\ \text{k}\Omega$
$V_{BE} = 0.7$ V

Solution:

$I_D = (V_{EE} - V_{BE})/R_E$ (Eq. 13-13)
$I_D = (9\ \text{V} - 0.7\ \text{V})/8.2\ \text{k}\Omega$
$I_D = 1.01$ mA

$V_D = V_{DD} - I_DR_D$ (Eq. 13-4)
$V_D = 15\ \text{V} - (1.01\ \text{mA})(7.5\ \text{k}\Omega)$
$V_D = 7.43$ V

Answer: The drain voltage is 7.43 V, and the drain current is 1.01 mA.

13-18. *Given:*

$V_{DD} = 15$ V
$V_{EE} = -9$ V
$R_D = 4.7\ \text{k}\Omega$
$R_E = 8.2\ \text{k}\Omega$
$V_{BE} = 0.7$ V

Solution:

$I_D = (V_{EE} - V_{BE})/R_E$ (Eq. 13-13)
$I_D = (9\text{ V} - 0.7\text{ V})/8.2\text{ k}\Omega$
$I_D = 1.01\text{ mA}$

$V_D = V_{DD} - I_D R_D$ (Eq. 13-4)
$V_D = 15\text{ V} - (1.01\text{ mA})(4.7\text{ k}\Omega)$
$V_D = 10.25\text{ V}$

Answer: The drain voltage is 10.25 V, and the drain current is 1.01 mA.

13-19. *Given:*

$V_{DD} = 25\text{ V}$
$R_D = 8.2\text{ k}\Omega$
$R_S = 1\text{ k}\Omega$
$I_D = 1.5\text{ mA}$

Solution:

$V_{GS} = -I_D R_S$ (Eq. 13-7)
$V_{GS} = -(1.5\text{ mA})(1\text{ k}\Omega)$
$V_{GS} = -1.5\text{ V}$

$V_D = V_{DD} - I_D R_D - I_D R_S$
$V_D = 25\text{ V} - (1.5\text{ mA})(8.2\text{ k}\Omega) - (1.5\text{ mA})(1\text{ k}\Omega)$
$V_D = 11.2\text{ V}$

Answer: The gate-source voltage is –1.5 V, and the drain-source voltage is 11.2 V.

13-20. *Given:*

$V_{DD} = 25\text{ V}$
$R_D = 8.2\text{ k}\Omega$
$R_S = 1\text{ k}\Omega$
$V_S = 1.5\text{ V}$

Solution:

$I_D = V_S/R_S$
$I_D = 1.5\text{ V}/1\text{ k}\Omega$
$I_D = 1.5\text{ mA}$

$V_D = V_{DD} - I_D R_D$
$V_D = 25\text{ V} - (1.5\text{ mA})(8.2\text{ k}\Omega)$
$V_D = 12.7\text{ V}$

Answer: The drain voltage is 12.7 V.

13-21. *Given:*

$V_{DD} = 25\text{ V}$
$R_D = 10\text{ k}\Omega$
$R_S = 22\text{ k}\Omega$
$R_1 = 1.5\text{ M}\Omega$
$R_2 = 1\text{ M}\Omega$

Answer: The gate-source voltage is –2.5 V, and the drain current is 0.55 mA.

13-22. *Given:*

$V_{DD} = 15\text{ V}$
$R_G = 2.2\text{ M}\Omega$
$R_E = 8.2\text{ k}\Omega$
$V_{EE} = -9\text{ V}$

Answer: The gate-source voltage is –2.0 V, and the drain voltage is 7.5 V.

13-23. *Given:*

$V_{DD} = 25\text{ V}$
$R_G = 1.5\text{ M}\Omega$
$R_S = 1\text{ k}\Omega$

Answer: The gate-source voltage is –2.0 V, and the drain current is 1.5 mA.

13-24. *Given:*

$V_{DD} = 25\text{ V}$
$R_G = 1.5\text{ M}\Omega$
$R_S = 2\text{ k}\Omega$

Answer: The gate-source voltage is –5.0 V, and the drain current is 1 mA and the drain-source voltage is 14.8 V.

13-25. *Given:*

$g_{m0} = 4000\ \mu\text{S}$
$I_{DSS} = 10\text{ mA}$

Solution:

$V_{GS(\text{off})} = -2\text{I}/_{\text{DSS}}/g_{m0}$ (Eq. 13-15)
$V_{GS(\text{off})} = -2(10\text{ mA})/4000\ \mu\text{S}$
$V_{GS(\text{off})} = -5\text{ V}$

$g_m = g_{m0}\,[1 - (V_{GS}/V_{GS(\text{off})})]$ (Eq.13-16)
$g_m = 4000\ \mu\text{S}[1 - (-1\text{ V}/-5\text{V})]$
$g_m = 3200\ \mu\text{S}$

Answer: The gate-source cutoff voltage is –5 V, and the g_{m0} for $V_{GS} = -1$ V is 3200 µS.

13-26. *Given:*

$g_{m0} = 1500\ \mu\text{S}$
$I_{DSS} = 2.5\text{ mA}$
$V_{GS} = -1\text{ V}$

Solution:

$V_{GS(\text{off})} = -2\text{I}_{DSS}/g_{m0}$ (Eq. 13-15)
$V_{GS(\text{off})} = -2(2.5\text{ mA})/1500\ \mu\text{S}$
$V_{GS(\text{off})} = -3.33\text{ V}$

$g_m = g_{m0}\,[1 - (V_{GS}/V_{GS(\text{off})})]$ (Eq. 13-16)
$g_m = 1500\ \mu\text{S}[1 - (-1\text{ V}/-3.3\text{ V})]$
$g_m = 1045\ \mu\text{S}$

Answer: The g_m for $V_{GS} = -1$ V is 1045 µS.

13-27. *Given:*

$g_{m0} = 6000\ \mu\text{S}$
$I_{DSS} = 12\text{ mA}$
$V_{GS} = -2\text{ V}$

Solution:

$V_{GS(\text{off})} = -2I_{DSS}/g_{m0}$ (Eq. 13-15)
$V_{GS(\text{off})} = -2(12\text{ mA})/6000\ \mu\text{S}$
$V_{GS(\text{off})} = -4\text{ V}$

Since the ratio of V_{GS} to $V_{GS(\text{off})}$ is one-half, the following equation can be used:

$I_D/I_{DSS} = 1/4$
$I_D = 1/4(I_{DSS})$
$I_D = 1/4(12\text{ mA})$
$I_D = 3\text{ mA}$

$g_m = g_{m0}\,[1 - (V_{GS}/V_{GS(\text{off})})]$ (Eq. 13-16)
$g_m = 6000\ \mu\text{S}[1 - (-2\text{ V}/-4\text{ V})]$
$g_m = 3000\ \mu\text{S}$

Answer: The drain current is 3 mA, and the transconductance is 3000 µS.

13-28. *Given:*

$V_{DD} = 30\text{ V}$
$R_1 = 20\text{ M}\Omega$
$R_2 = 10\text{ M}\Omega$
$R_D = 1\text{ k}\Omega$
$R_S = 2\text{ k}\Omega$
$R_L = 10\text{ k}\Omega$
$v_{\text{in}} = 2\text{ mV}$
$g_m = 3000\ \mu\text{S}$

Solution:

$r_d = R_D \| R_L$
$r_d = 1\text{ k}\Omega \| 10\text{ k}\Omega$
$r_d = 909\ \Omega$

$A_v = g_m r_d$ (Eq. 13-17)
$A_v = (3000\ \mu S)(909\ \Omega)$
$A_v = 2.73$

$v_{out} = A_v(v_{in})$
$v_{out} = (2.73)(2\text{ mV})$
$v_{out} = 5.46\text{ mV}$

Answer: The output voltage is 5.46 mV.

13-29. *Given:*

$V_{DD} = 30\text{ V}$
$R_1 = 20\text{ M}\Omega$
$R_2 = 10\text{ M}\Omega$
$R_D = 1\text{ k}\Omega$
$R_S = 2\text{ k}\Omega$
$R_L = 10\text{ k}\Omega$
$v_{in} = 2\text{ mV}$
$I_{DSS} = 12\text{ mA}$ (from the graph)
$V_{GS(off)} = –4\text{ V}$ (from the graph)

Solution:

$r_d = R_D \| R_L$
$r_d = 1\text{ k}\Omega \| 10\text{ k}\Omega$
$r_d = 909\ \Omega$

$V_{GS(off)} = –2I_{DSS}/g_{m0}$ (Eq. 13-15)
$g_{m0} = -2I_{DSS}/V_{GS(off)}$
$g_{m0} = –2(12\text{ mA})/–4\text{ V}$
$g_{m0} = 6000\ \mu S$

$V_G = [R_2/(R_1 + R_2)]V_{DD}$
$V_G = [10\text{ M}\Omega/(20\text{ M}\Omega + 10\text{ M}\Omega)]\ 30\text{ V}$
$V_G = 10\text{ V}$

$I_D = V_G/R_S$ (Eq. 13-10)
$I_D = 10\text{ V}/2\text{ k}\Omega$
$I_D = 5\text{ mA}$

From the graph, V_{GS} is approximately –1.4 V when I_D is 5 mA.

With Eq. 13-16, $g_{m0} = 3900\ \mu S$. Then:

$A_v = g_m r_d$ (Eq. 13-17)
$A_v = (3900\ \mu S)(909\ \Omega)$
$A_v = 3.54$

$v_{out} = A_v(v_{in})$
$v_{out} = 3.54(2\text{ mV})$
$v_{out} = 7.09\text{ mV}$

Answer: The output voltage is 7.09 mV.

13-30. *Given:*

$V_{DD} = 30\text{ V}$
$R_1 = 20\text{ M}\Omega$
$R_2 = 10\text{ M}\Omega$
$R_S = 3.3\text{ k}\Omega$
$R_L = 1\text{ k}\Omega$
$v_{in} = 5\text{ mV}$
$g_m = 2000\ \mu S$

Solution:

$r_S = R_S \| R_L$
$r_S = 3.3\text{ k}\Omega \| 1\text{ k}\Omega$
$r_S = 767\ \Omega$

$A_v = (g_m r_s)/(1 + g_m r_s)$ (Eq. 13-18)
$A_v = (2000\ \mu S)(767\ \Omega)/[1 + (2000\ \mu S)(767\ \Omega)]$
$A_v = 0.605$

$v_{out} = A_v(v_{in})$
$v_{out} = (0.605)(5\text{ mV})$ This Is Good
$v_{out} = 3.03\text{ mV}$

Answer: The output voltage is 3.03 mV.

13-31. *Given:*

$V_{DD} = 30\text{ V}$
$R_1 = 20\text{ M}\Omega$
$R_2 = 10\text{ M}\Omega$
$R_S = 3.3\text{ k}\Omega$
$R_L = 1\text{ k}\Omega$
$v_{in} = 5\text{ mV}$
$I_{DSS} = 6\text{ mA}$ (from the graph)
$V_{GS(off)} = –4\text{ V}$ (from the graph)
$r_S = 767\ \Omega$ (from Prob. 13-30)

Solution:

$V_{GS(off)} = –2I_{DSS}/g_{m0}$ (Eq. 13-15)
$g_{m0} = –2I_{DSS}/V_{GS(off)}$
$g_{m0} = –2(6\text{ mA})/ –4\text{ V}$
$g_{m0} = 3000\ \mu S$

$V_G = [R_2/(R_1 + R_2)]V_{DD}$
$V_G = [10\text{ M}\Omega/(20\text{ M}\Omega + 10\text{ M}\Omega)]\ 30\text{ V}$
$V_G = 10\text{ V}$

$I_D = V_G/R_S$ (Eq. 13-7)
$I_D = 10\text{ V}/3.3\text{ k}\Omega$
$I_D \cong 3\text{ mA}$

From the graph, V_{GS} is roughly –1.25 V when I_D = 3 mA. With Eq. (13-16), $g_m = 2060\ \mu S$.

With Eq. (13-18):

$g_m r_S = (2060\ \mu S)(767\ \Omega) = 1.58$
$A_v = 1.58/(1 + 1.58) = 0.612$

$v_{out} = A_{vin}$
$v_{out} = (0.612)(5\text{ mV})$
$v_{out} = 3.06\text{ mV}$

Answer: The output voltage is 3.06 mV.

13-32. *Given:*

$R_{in} = 22\text{ k}\Omega$
$v_{in} = 50\text{ mV pp}$
$I_{DSS} = 10\text{ mA}$
$V_P = 2\text{ V}$

Solution:

$R_{DS} = V_P/I_{DSS}$ (Eq. 13-1)
$R_{DS} = 2\text{ V}/10\text{ mA}$
$R_{DS} = 200\ \Omega$

With V_{GS} at –10 V the JFET is cut off and appears as an open; thus $v_{out} = v_{in} = 50$ mV pp.

With V_{GS} at 0 V, the JFET is conducting and a voltage divider is created with the input resistance.

$v_{out} = [R_{DS}/(R_{DS} + R_{in})]v_{in}$
$v_{out} = [200\ \Omega/(200\ \Omega + 22\text{ k}\Omega)]50\text{ mV pp}$
$v_{out} = 0.45\text{ mV pp}$

On-off ratio = $v_{out(max)}/v_{out(min)}$ (Eq. 13-19)
On-off ratio = 50 mV pp/0.45 mV pp
On-off ratio =111

Answer: The output voltage at a V_{GS} of –10 V is 50 mV pp, the output voltage at a V_{GS} of 0 V is 0.45 mV pp, and the on-off ratio is 111.

13-33. *Given:*

$R_{out} = 33\text{ k}\Omega$
$v_{in} = 25\text{ mV pp}$
$I_{DSS} = 5\text{ mA}$
$V_P = 3\text{ V}$

Solution:

$R_{DS} = V_P/I_{DSS}$ (Eq. 13-1)

R_{DS} = 3 V/5 mA
R_{DS} = 600 Ω

With V_{GS} at –10 V the JFET is cut off and appears as an open; thus v_{in} = 0 mV pp.

With V_{GS} at 0 V, the JFET is conducting and a voltage divider is created with the output resistance.

$v_{out} = [R_{out}/(R_{DS} + R_{out})]v_{in}$
v_{out} = [33 kΩ/(600 Ω + 33 kΩ)]25 mV pp
v_{out} = 24.55 mV pp

On-off ratio = $v_{out(max)}/v_{out(min)}$ (Eq. 13-19)
On-off ratio = 24.55 mV pp/0 mV pp
On-off ratio = ∞

Answer: The output voltage at a V_{GS} of –10 V is 0 mV pp, the output voltage at a V_{GS} of 0 V is 24.55 mV pp, and the on-off ratio is ∞.

CRITICAL THINKING

13-34. *Answer:*

I_{DSS} = 20 mA
$V_{DS(max)}$ = 5 V for the ohmic region
V_{DS} = 5 to 30 V in the active range

13-35. *Given:*

$V_{GS(off)}$ = –8 V (from the graph)
I_{DSS} = 32 mA (from the graph)
$V_{GS(1)}$ = –4 V
$V_{GS(2)}$ = –2 V

Solution:

$V_{GS(off)} = -2I_{DSS}/g_{m0}$ (Eq. 13-15)
$g_{m0} = -2I_{DSS}/V_{GS(off)}$
g_{m0} = –2(32 mA)/–8 V
g_{m0} = 8000 µS

$g_m = g_{m0}\,[1 - (V_{GS}/V_{GS(off)})]$ (Eq. 13-16)
g_m = 8000 µS$[1 - (V_{GS}/–8\text{ V})]$

$I_D = I_{DSS}[1 - (V_{GS(1)}/V_{GS(off)})]^2$ (Eq. 13-3)
I_D = 32 mA$[1 - (–4\text{ V}/–8\text{V})]^2$
I_D = 8 mA

$I_D = I_{DSS}[1 - (V_{GS(2)}/V_{GS(off)})]^2$ (Eq. 13-3)
I_D = 32 mA$[1 - (–2\text{ V}/–8\text{V})]^2$
I_D = 8 mA

Answer: The transconductance equation is g_m = 8000 µS $[1 - (V_{GS}/–8\text{ V})]$, the drain current at –4 V is 8 mA, and the drain current at –2 V is 18 mA.

13-36. *Given:*

$V_{GS(off)}$ = –5 V (from the graph)
I_{DSS} = 12 mA (from the graph)
$V_{GS(1)}$ = –1 V

Solution:

$I_D = I_{DSS}[1 - (V_{GS(1)}/V_{GS(off)})]^2$ (Eq. 13-3)
I_D = 12 mA$[1 - (–1\text{ V}/–5\text{V})]^2$
I_D = 7.68 mA

Answer: The drain current is 7.68 mA.

13-37. *Given:*

V_{DD} = 15 V
V_{EE} = –10 V
R_D = 3.3 kΩ
R_E = 4.7 kΩ
V_{BE} = 0.7 V
g_m = 2000 µS
v_{in} = 3 mV

Solution:

$I_D = (V_{EE} - V_{BE})/R_E$ (Eq. 13-13)
I_D = (10 V – 0.7 V)/4.7 kΩ
I_D = 2 mA

$V_D = V_{DD} - I_DR_D$ (Eq. 13-4)
V_D = 15 V – (2 mA)(3.3 kΩ)
V_D = 8.4 V

$r_d = R_D \| R_L$
r_d = 3.3 kΩ‖15 kΩ
r_d = 2.7 kΩ

$A_v = g_m r_d$ (Eq. 13-17)
A_v = (2000 µS)(2.7 kΩ)
A_v = 5.4

$v_{out} = A_v(v_{in})$
v_{out} = (5.4)(3 mV)
v_{out} = 16.2 mV

Answer: The drain voltage is 8.4 V, and the output voltage is 16.2 mV.

13-38. *Answer:*

a. Multiply 4 mA and 510 Ω to get 2.04 V.
b. It must equal 2.04 V.
c. Because of the linearity of the circuit, the meter reads half of maximum, or 0.5 mA.

13-39. *Given:*

I_{DSS} = 16 mA
R_{DS} = 200 Ω
R_L = 10 kΩ
V_{DD} = 30 V

Solution: Since V_{GS} is 0 V, it is operating in the active region. The JFET appears to be a current source, but since the load is so large, the power supply cannot supply enough voltage to produce that current and it drops into the ohmic region and the JFET acts like resistor.

$I = V_{DD}/(R_{DS} + R_L)$
I = 30 V/(200 Ω + 10 kΩ)
I = 2.94 mA

$V_{DS} = IR_{DS}$
V_{DS} = (2.94 mA)(200 Ω)
V_{DS} = 0.59 V

If the load is shorted, R_L = 0 Ω and the JFET operates in the active region.

$I = I_{DSS}$
I = 16 mA

$V_{DS} = V_{DD}$
V_{DS} = 30 V

Answer: During normal operation, the current is 2.94 mA and the voltage across the JFET is 0.59 V. With the load shorted, the current is 16 mA and the voltage is 30 V.

13-40. *Answer:*

a. The g_{m0} is 6000 µS. Multiply this by 1 kΩ to get a voltage gain of 6.
b. At –1 V, the g_m is 4500 µS and the voltage gain is 4.5.
c. 3
d. 1.5
e. 0.75

$I_D = I_{DSS}(1 - (V_{GS}/V_{GS(\text{off})}))^2$
$I_D = 4 \text{ mA}(1 - (-1 \text{ V}/-2.0 \text{ V}))^2$
$I_D = 1 \text{ mA}$

$I_D = I_{DSS}(1 - (V_{GS}/V_{GS(\text{off})}))^2$
$I_D = 4 \text{ mA}(1 - (-1.5 \text{ V}/-2.0 \text{ V}))^2$
$I_D = 0.25 \text{ mA}$

Answer:

$V_{GS} = -0.5 \text{ V}, I_D = 2.25 \text{ mA}$
$V_{GS} = -1 \text{ V}, \quad I_D = 1 \text{ mA}$
$V_{GS} = -1.5 \text{ V}, I_D = 250 \text{ mA}$

14-2. *Given:*

$V_{GS} = -0.5 \text{ V}$
$V_{GS} = -1.0 \text{ V}$
$V_{GS} = -1.5 \text{ V}$
$V_{GS} = +0.5 \text{ V}$
$V_{GS} = +1.0 \text{ V}$
$V_{GS} = +1.5 \text{ V}$
$V_{GS(\text{off})} = -2 \text{ V}$
$I_{DSS} = 4 \text{ mA}$

Solution:

$I_D = I_{DSS}(1 - (V_{GS}/V_{GS(\text{off})}))^2$ (Eq. 14-1)
$I_D = 4 \text{ mA}(1 - (+0.5 \text{ V}/-2.0 \text{ V}))^2$
$I_D = 6.25 \text{ mA}$

$I_D = I_{DSS}(1 - (V_{GS}/V_{GS(\text{off})}))^2$ (Eq. 14-1)
$I_D = 4 \text{ mA}(1 - (+1 \text{ V}/-2.0 \text{ V}))^2$
$I_D = 9 \text{ mA}$

$I_D = I_{DSS}(1 - (V_{GS}/V_{GS(\text{off})}))^2$ (Eq. 14-1)
$I_D = 4 \text{ mA}(1 - (+1.5 \text{ V}/-2.0 \text{ V}))^2$
$I_D = 12.25 \text{ mA}$

Answer:

$V_{GS} = 0.5 \text{ V}, I_D = 6.25 \text{ mA}$
$V_{GS} = 1 \text{ V}, \quad I_D = 9 \text{ mA}$
$V_{GS} = 1.5 \text{ V}, I_D = 12.25 \text{ mA}$

14-3. *Given:*

$V_{GS} = -1.0 \text{ V}$
$V_{GS} = -2.0 \text{ V}$
$V_{GS} = 0 \text{ V}$
$V_{GS} = +1.5 \text{ V}$
$V_{GS} = +2.5 \text{ V}$
$V_{GS(\text{off})} = +3 \text{ V}$
$I_{DSS} = 12 \text{ mA}$

Solution:

$I_D = I_{DSS}(1 - (V_{GS}/V_{GS(\text{off})}))^2$ (Eq. 14-1)
$I_D = 4 \text{ mA}(1 - (+1.5 \text{ V}/+3.0\text{V}))^2$
$I_D = 3 \text{ mA}$

$I_D = I_{DSS}(1 - (V_{GS}/V_{GS(\text{off})}))^2$ (Eq. 14-1)
$I_D = 4 \text{ mA}(1 - (2.5 \text{ V}/+3.0 \text{ V}))^2$
$I_D = 0.333 \text{ mA}$

Answer:

$V_{GS} = 1.5 \text{ V}, I_D = 3 \text{ mA}$
$V_{GS} = 2.5 \text{ V}, I_D = 333 \ \mu\text{A}$

14-4. *Given:*

$V_{GS(\text{off})} = -3 \text{ V}$
$I_{DSS} = 12 \text{ mA}$

Solution:

$V_{DS} = V_{DD} - (I_{DSS}R_D)$ (Eq. 14-2)
$V_{DS} = 12 \text{ V} - ((12 \text{ mA})(470 \ \Omega))$
$V_{DS} = 6.36 \text{ V}$

$I_D = I_{DSS} = 12 \text{ mA}$

Answer: The drain current is 12 mA and the drain-source voltage is 6.36 V.

14-5. *Given:*

$g_{m0} = 4000 \ \mu\text{S}$
$R_D = 470 \ \Omega$
$R_L = 2 \text{ k}\Omega$
$V_{\text{in}} = 100 \text{ mV}$

Solution:

$r_d = R_D || R_L$
$r_d = 470 \ \Omega || 2 \text{ k}\Omega$
$r_d = 381 \ \Omega$

$A_v = g_m r_d$
$A_v = (4000 \ \mu\text{S})(381 \ \Omega)$
$A_v = 1.52$

$v_{\text{out}} = V_{\text{in}} A_v$
$v_{\text{out}} = (100 \text{ mV})(1.52)$
$v_{\text{out}} = 152 \text{ mV}$

Answer: The voltage gain is 1.52, the voltage out is 152 mV, and r_d is 381 Ω.

14-6. *Given:*

$g_{m0} = 4000 \ \mu\text{S}$
$R_D = 680 \ \Omega$
$R_L = 10 \text{ k}\Omega$
$V_{\text{in}} = 100 \text{ mV}$

Solution:

$r_d = R_D || R_L$
$r_d = 680 \ \Omega || 10 \text{ k}\Omega$
$r_d = 637 \ \Omega$

$A_v = g_m r_d$
$A_v = (4000 \ \mu\text{S})(637 \ \Omega)$
$A_v = 2.55$

$v_{\text{out}} = V_{\text{in}} A_v$
$v_{\text{out}} = (100 \text{ mV})(2.55)$
$v_{\text{out}} = 255 \text{ mV}$

Answer: The voltage gain is 2.55, the voltage out is 255 mV, and r_d is 637 Ω.

14-7. *Given:*

$g_{m0} = 4000 \ \mu\text{S}$
$R_D = 680 \ \Omega$
$R_L = 10 \text{ k}\Omega$
$V_{\text{in}} = 100 \text{ mV}$
$R_G = 1 \text{ M}\Omega$

Solution:

$Z_{\text{in}} \approx R_G \approx 1 \text{ M}\Omega$

Answer: The input impedance is approximately 1 MΩ.

14-8a. *Given:*

$V_{DS(\text{on})} = 0.1 \text{ V}$
$I_{D(\text{on})} = 10 \text{ mA}$

Solution:

$R_{DS(\text{on})} = V_{DS(\text{on})}/I_{D(\text{on})}$ (Eq. 14-1)
$R_{DS(\text{on})} = 0.1 \text{ V}/10 \text{ mA}$
$R_{DS(\text{on})} = 10 \ \Omega$

Answer: The drain-source resistance is 10 Ω.

14-8b. *Given:*

$V_{DS(\text{on})} = 0.25 \text{ V}$
$I_{D(\text{on})} = 45 \text{ mA}$

Solution:

$R_{DS(\text{on})} = V_{DS(\text{on})}/I_{D(\text{on})}$ (Eq. 14-1)
$R_{DS(\text{on})} = 0.25\text{ V}/45\text{ mA}$
$R_{DS(\text{on})} = 5.56\ \Omega$

Answer: The drain-source resistance is 5.56 Ω.

14-8c. *Given:*

$V_{DS(\text{on})} = 0.75\text{ V}$
$I_{D(\text{on})} = 100\text{ mA}$

Solution:

$R_{DS(\text{on})} = V_{DS(\text{on})}/I_{D(\text{on})}$ (Eq. 14-1)
$R_{DS(\text{on})} = 0.75\text{ V}/100\text{ mA}$
$R_{DS(\text{on})} = 7.5\ \Omega$

Answer: The drain-source resistance is 7.5 Ω.

14-8d. *Given:*

$V_{DS(\text{on})} = 0.15\text{ V}$
$I_{D(\text{on})} = 200\text{ mA}$

Solution:

$R_{DS(\text{on})} = V_{DS(\text{on})}/I_{D(\text{on})}$ (Eq. 14-1)
$R_{DS(\text{on})} = 0.15\text{ V}/200\text{ mA}$
$R_{DS(\text{on})} = 0.75\ \Omega$

Answer: The drain-source resistance is 0.75 Ω.

14-9a. *Given:*

$V_{GS(\text{on})} = 3\text{ V}$
$I_{D(\text{on})} = 500\text{ mA}$
$R_{DS(\text{on})} = 2\ \Omega$
$I_{D(\text{Sat})} = 25\text{ mA}$

Solution:

$V_{DS} = I_{D(\text{Sat})}R_{DS(\text{on})}$
$V_{DS} = 25\text{ mA }(2\ \Omega)$
$V_{DS} = 0.05\text{ V}$

Answer: The voltage across the E-MOSFET is 0.05 V.

14-9b. *Given:*

$V_{GS(\text{on})} = 3\text{ V}$
$I_{D(\text{on})} = 500\text{ mA}$
$R_{DS(\text{on})} = 2\ \Omega$
$I_{D(\text{Sat})} = 50\text{ mA}$

Solution:

$V_{DS} = I_{D(\text{Sat})}R_{DS(\text{on})}$
$V_{DS} = 50\text{ mA }(2\ \Omega)$
$V_{DS} = 0.1\text{ V}$

Answer: The voltage across the E-MOSFET is 0.1 V.

14-9c. *Given:*

$V_{GS(\text{on})} = 3\text{ V}$
$I_{D(\text{on})} = 500\text{ mA}$
$R_{DS(\text{on})} = 2\ \Omega$
$I_{D(\text{Sat})} = 100\text{ mA}$

Solution:

$V_{DS} = I_{D(\text{Sat})}R_{DS(\text{on})}$
$V_{DS} = 100\text{ mA }(2\ \Omega)$
$V_{DS} = 0.2\text{ V}$

Answer: The voltage across the E-MOSFET is 0.2 V.

14-9d. *Given:*

$V_{GS(\text{on})} = 3\text{ V}$
$I_{D(\text{on})} = 500\text{ mA}$
$R_{DS(\text{on})} = 2\ \Omega$
$I_{D(\text{Sat})} = 200\text{ mA}$

Solution:

$V_{DS} = I_{D(\text{Sat})}R_{DS(\text{on})}$
$V_{DS} = 200\text{ mA }(2\ \Omega)$
$V_{DS} = 0.4\text{ V}$

Answer: The voltage across the E-MOSFET is 0.4 V.

14-10. *Given:*

$V_{GS(\text{on})} = 2.5\text{ V}$ (from Table 14-1)
$I_{D(\text{on})} = 100\text{ mA}$ (from Table 14-1)
$R_{DS(\text{on})} = 10\ \Omega$ (from Table 14-1)
$V_{DD} = 20\text{ V}$
$R_D = 390\ \Omega$

Solution:

$V_D = [R_{DS(\text{on})}/(R_{DS(\text{on})} + R_D)]V_{DD}$
$V_D = [10\ \Omega/(10\ \Omega + 390\ \Omega)]20\text{ V}$
$V_D = 0.5\text{ V}$

Answer: The voltage across the E-MOSFET is 0.5 V.

14-11. *Given:*

$V_{GS(\text{on})} = 2.6\text{ V}$ (from Table 14-1)
$I_{D(\text{on})} = 20\text{ mA}$ (from Table 14-1)
$R_{DS(\text{on})} = 28\ \Omega$ (from Table 14-1)
$V_{DD} = 15\text{ V}$
$R_D = 1.8\text{ k}\Omega$

Solution:

$V_D = [R_{DS(\text{on})}/(R_{DS(\text{on})} + R_D)]V_{DD}$
$V_D = [28\ \Omega/(28\ \Omega + 1.8\text{ k}\Omega)]15\text{ V}$
$V_D = 0.23\text{ V}$

Answer: The drain voltage is 0.23 V.

14-12. *Given:*

$V_{GS(\text{on})} = 5\text{ V}$ (from Table 14-1)
$I_{D(\text{on})} = 200\text{ mA}$ (from Table 14-1)
$R_{DS(\text{on})} = 7.5\ \Omega$ (from Table 14-1)
$V_{DD} = 25\text{ V}$
$R_D = 150\ \Omega$

Solution:

$V_D = [R_D/(R_{DS(\text{on})} + R_D)]V_{DD}$
$V_D = [150\ \Omega/(7.5\ \Omega + 150\ \Omega)]\ 25\text{ V}$
$V_D = 23.8\text{ V}$

Answer: The drain voltage is 23.8 V.

14-13. *Given:*

$V_{GS(\text{on})} = 10\text{ V}$ (from Table 14-1)
$I_{D(\text{on})} = 1\text{ A}$ (from Table 14-1)
$R_{DS(\text{on})} = 0.9\ \Omega$ (from Table 14-1)
$V_{DD} = 12\text{ V}$
$R_D = 18\ \Omega$

Solution:

$V_D = [R_{DS(\text{on})}/(R_{DS(\text{on})} + R_D)]V_{DD}$
$V_D = [0.9\ \Omega/(0.9\ \Omega + 18\ \Omega)]12\text{ V}$
$V_D = 0.57\text{ V}$

Answer: The drain voltage is 0.57 V.

14-14. *Given:*

$V_{GS(\text{on})} = 5\text{ V}$ (from Table 14-1)
$I_{D(\text{on})} = 200\text{ mA}$ (from Table 14-1)
$R_{DS(\text{on})} = 7.5\ \Omega$ (from Table 14-1)
$V_{DD} = 30\text{ V}$
$R_D = 1\text{ k}\Omega$
$V_{\text{LED}} = 2\text{ V}$

Solution:

$I_D = (V_{DD} - V_{LED})/(R_{DS(on)} + R_D)$
$I_D = (30\text{ V} - 2\text{ V})/(7.5\ \Omega + 1\text{ k}\Omega)$
$I_D = 27.8\text{ mA}$

Answer: The LED current is 27.8 mA.

14-15. *Given:*

$V_{GS(on)} = 2.6\text{ V}$ (from Table 14-1)
$I_{D(on)} = 20\text{ mA}$ (from Table 14-1)
$R_{DS(on)} = 28\ \Omega$ (from Table 14-1)
$V_{DD} = 20\text{ V}$
$R_D = 1\text{ k}\Omega$

Solution:

$I_D = (V_{DD})/(R_{DS(on)} + R_D)$
$I_D = (20\text{ V})/(28\ \Omega + 1\text{ k}\Omega)$
$I_D = 19.5\text{ mA}$

$I_L = V_{DD}/R_L$
$I_L = 20\text{ V}/2\ \Omega$
$I_L = 10\text{ A}$

Answer: The MOSFET current is 19.5 mA. The load current is 10 A.

14-16. *Given:*

$I_{D(active)} = 1\text{ mA}$
$V_{DS(active)} = 10\text{ V}$

Solution:

$R_D = V_{DS(active)}/I_{D(active)}$ (Eq. 14-6)
$R_D = 10\text{ V}/1\text{ mA}$
$R_D = 10\text{ k}\Omega$

Answer: The drain resistance is 10 kΩ.

14-17. *Given:*

$R_{DS(on)} = 300\ \Omega$
$V_{DD} = 12\text{ V}$
$R_D = 8\text{ k}\Omega$

Solution: When the input is low, the lower MOSFET is open and the output voltage is pulled up to the supply voltage. When the input is high, the lower MOSFET has a resistance of 300 Ω.

$v_{out} = [R_{DS(on)}/(R_{DS(on)} + R_D)]\text{V}_{DD}$
$v_{out} = [300\ \Omega/(300\ \Omega + 8\text{ k}\Omega)]12\text{ V}$
$v_{out} = 0.43\text{ V}$

Answer: When the input voltage is low, the output voltage is 12 V; when the input voltage is high, the output voltage is 0.43 V.

14-18. *Given:*

$R_{DS(on)} = 150\ \Omega$
$V_{DD} = 18\text{ V}$
$R_D = 2\text{ k}\Omega$

Solution: When the input is low, the lower MOSFET is open and the output voltage is pulled up to the supply voltage. When the input is high, the lower MOSFET has a resistance of 150 Ω.

$v_{out} = [R_{DS(on)}/(R_{DS(on)} + R_D)]V_{DD}$
$v_{out} = [150\ \Omega/(150\ \Omega + 2\text{ k}\Omega)]18\text{ V}$
$v_{out} = 1.26\text{ V}$

Answer: When the input voltage is low, the output voltage is 18 V; when the input voltage is high, the output voltage is 1.26 V.

14-19. *Answer:* The output waveform is a square wave with an upper peak of +12 V and a lower peak of 0.43 V.

14-20. *Answer:* Inverted.

14-21. *Answer:* The on MOSFET has an $R_{DS(on)}$ of 10 V divided by 1 mA, which equals 10 kΩ. The off MOSFET has an $R_{DS(off)}$ of 10 V divided by 1 μA, which equals 10 MΩ. When the input voltage is high, the lower MOSFET is on, and the output voltage is given by:

$$V_{out} = \frac{10\text{ k}\Omega}{10.01\text{ M}\Omega}12\text{ V} \cong 0.012\text{ V}$$

When the input voltage is low, the lower MOSFET is off, and the output voltage is given by:

$$V_{out} = \frac{10\text{ M}\Omega}{10.01\text{ M}\Omega}12\text{ V} \cong 12\text{ V}$$

14-22. *Given:*

12-V peak square-wave input
$f = 1\text{ kHz}$

Assume the same values from the previous problem.

Answer: The signal will be 180° out of phase and have a maximum value of 12 V and a minimum value of 0 V.

14-23. *Given:*

$V_{DD} = 12\text{ V}$
$R_{DS(on)} = 5\text{ k}\Omega$

Solution:

$I_D = V_{DD}/2(R_{DS(on)})$
$I_D = 12\text{ V}/2(5\text{ k}\Omega)$
$I_D = 1.2\text{ mA}$

Answer: The current is 1.2 mA.

14-24. *Given:*

$V_{GS(on)} = 10\text{ V}$ (from Table 14-2)
$I_{D(on)} = 2\text{ A}$ (from Table 14-2)
$R_{DS(on)} = 1.95\ \Omega$ (from Table 14-2)
$V_{DD} = 12\text{ V}$
$R_D = 10\ \Omega$

Solution: When the input is low, the MOSFET is open and no current flows. When the input is high, the MOSFET has a resistance of $R_{DS(on)} = 1.95\ \Omega$.

$I_D = (V_{DD})/(R_{DS(on)} + R_D)$
$I_D = (12\text{ V})/(1.95\ \Omega + 10\ \Omega)$
$I_D = 1\text{ A}$

Answer: The current is 0 A when the input is low, and 1 A when the input is high.

14-25. *Given:*

$V_{GS(on)} = 10\text{ V}$ (from Table 14-2)
$I_{D(on)} = 2\text{ A}$ (from Table 14-2)
$R_{DS(on)} = 1.95\ \Omega$ (from Table 14-2)
$V_{DD} = 12\text{ V}$
$R_D = 6\ \Omega$

Solution: When the input is high, the MOSFET has a resistance of $R_{DS(on)} = 1.95\ \Omega$.

$I_D = (V_{DD})/(R_{DS(on)} + R_D)$
$I_D = (12\text{ V})/(1.95\ \Omega + 6\ \Omega)$
$I_D = 1.51\text{ A}$

Answer: The current is 1.51 A when the input is high.

14-26. *Given:*

$V_{GS(on)} = 10\text{ V}$ (from Table 14-2)
$I_{D(on)} = 5\text{ A}$ (from Table 14-2)
$R_{DS(on)} = 1.07\ \Omega$ (from Table 14-2)

Solution: As the temperature rises 100°C, the normalized resistance increases by a factor of 2.25. Thus 2.25/100°C = 0.0225/°C. The temperature increases 75°C. Thus the resistance increases by a factor of 75°C(0.0225/°C) = 1.69.

0.17(1.69) = 0.29 Ω

Answer: The resistance at 100°C is 0.29 Ω.

14-41. *Given:*

V_{in} = 12 V
Turns ratio = 4:1

Solution: The primary voltage will be 12 V.

$N_1/N_2 = 4$
$N_1/N_2 = V_1/V_2$ (Eq. 4-14)
$V_2 = V_1/(N_1/N_2)$
V_2 = 12 V/4
V_2 = 3 V

Answer: The output voltage is 3 V.

Chapter 15 Thyristors

SELF-TEST

1. c	**9. b**	**17. d**	**25. d**
2. b	**10. c**	**18. a**	**26. d**
3. d	**11. a**	**19. a**	**27. b**
4. c	**12. b**	**20. b**	**28. a**
5. b	**13. b**	**21. c**	**29. c**
6. b	**14. d**	**22. b**	**30. b**
7. a	**15. d**	**23. c**	**31. a**
8. b	**16. d**	**24. b**	

JOB INTERVIEW QUESTIONS

5. The SCR remains latched once the initial stimulus is removed; the transistor does not. This prevents silencing the alarm by a clever burglar or destruction of the sending unit by fire or flood, etc.

6. In every section of the field.

7. Power-handling capability: The SCR can handle the most current, and the power FET the least current. Efficiency: The SCR is the most efficient since the control signal can be removed once SCR is conducting, and the power FET is the next-most efficient since its control current is low. Control input: The power FET and BJT are easier to control because they can be shut off using the control input. Maximum frequency: The power FET switches the fastest.

PROBLEMS

15-1. *Given:*

V_D = 0.7 V
I_H = 4 mA
R = 1 kΩ

Solution:

$V = I_H R$ + 0.7 V (Eq. 15-2)
V = (4 mA)(1 kΩ) + 0.7 V
V = 4.7 V

Answer: The power supply voltage will be 4.7 V at dropout.

15-2. *Given:*

V_D = 0.7 V
V_B = 12 V
V = 19 V
R = 5 kΩ

Solution: Just before breakover, the capacitor voltage is V_B.

$I = (V - V_B)/R$
I = (19 V – 12 V)/5 kΩ
I = 1.4 mA

While the diode is conducting, the voltage across it is 0.7 V.

$I = (V - V_D)/R$
I = (19 V – 0.7 V)/5 kΩ
I = 3.66 mA

Answer: The current through the resistor just before breakover is 1.4 mA, and during conduction is 3.66 mA.

15-3. *Given:*

V_D = 0.7 V
V_B = 12 V
V = 19 V
R = 5 kΩ
C = 0.2 μF

Solution:

RC = (5 kΩ)(0.02 μF)
RC = 0.1 ms
T = 0.1 ms since the period equals the RC time

f = 1/T
f = 1/10.1 ms
f = 10 kHz

Answer: The RC time is 0.1 ms, and the frequency is 10 kHz.

15-4. *Given:*

V_D = 0.7 V
V_B = 20 V
I_H = 3 mA
R = 1 kΩ

Solution: Since the diode is open before breakover, no current flows before the device breaks over. Thus when the power supply reaches breakover voltage, the device will break over.

$V = I_H R$ + 0.7 V (Eq. 15-2)
V = (3 mA)(1 kΩ) + 0.7 V
V = 3.7 V

Answer: The power supply voltage will be 20 V at breakover and 3.7 V at dropout.

15-5. *Given:*

V_D = 0.7 V
V_B = 12 V
V = 19 V
R = 10 kΩ
C = 0.06 μF

Solution: The maximum voltage across the capacitor will be breakover voltage, because as soon as the device breaks over, the voltage drops to about 0.7 V.

RC = (10 kΩ)(0.06 μF)
RC = 0.6 ms

Answer: The maximum voltage across the capacitor is 12 V, and the time constant is 0.6 ms.

15-6. *Given:*

$V_{GT} = 1.0$ V
$I_{GT} = 2$ mA
$I_H = 12$ mA
$V_{CC} = 12$ V
$R_G = 2.2$ kΩ
$R = 47$ Ω

Solution: When the SCR is off, no current flows. The output voltage when the SCR is off is the same as the power supply voltage.

$V_{in} = V_{GT} + I_{GT}R_G$ (Eq. 15-1)
$V_{in} = 1\text{ V} + (2\text{ mA})(2.2\text{ k}\Omega)$
$V_{in} = 5.4$ V

$V = I_H R + 0.7$ V (Eq. 15-2)
$V_{CC} = (12\text{ mA})(47\ \Omega) + 0.7$ V
$V_{CC} = 1.26$ V

Answer: The output voltage when the SCR is off is 12 V. The input voltage required to turn on the SCR is 5.4 V, and the supply voltage required to turn the SCR off is 1.26 V.

15-7. *Given:*

$V_{GT} = 0.7$ V
$I_{GT} = 1.5$ mA
$I_H = 2$ mA
$V_{CC} = 12$ V
$R_G = 4.4$ kΩ
$R = 94$ Ω

Solution:

$V_{in} = V_{GT} + I_{GT}R_G$ (Eq. 15-1)
$V_{in} = 0.7\text{ V} + (1.5\text{ mA})(4.4\text{ k}\Omega)$
$V_{in} = 7.3$ V

Answer: The input voltage required to turn on the SCR is 7.3 V.

15-8. *Answer:* The highest output occurs when 0.8 V is across the 500-Ω resistor. The current through this resistor is 0.8 V divided by 500 Ω, which equals 1.6 mA. This 1.6 mA must flow through the 3.3-kΩ resistor. The 200 μA of gate current must also flow through the 3.3-kΩ resistor. If we ignore the 200 μA on the grounds that it is much smaller than 1.6 mA, we get an approximate answer of:

$$V = 0.8\text{ V} + (1.6\text{ mA})(3.3\text{ k}\Omega) = 6.08\text{ V}$$

If we include the 200 μA, we get a slightly larger output voltage:

$$V = 0.8\text{ V} + (1.6\text{ mA} + 200\ \mu\text{A})(3.3\text{ k}\Omega) = 6.74\text{ V}$$

15-9. *Given:*

$V_{GT} = 1.5$ V
$I_{GT} = 15$ mA
$I_H = 10$ mA
$V_{CC} = 12$ V
$R_G = 2.2$ kΩ
$R = 47$ Ω

Solution:

$V_{in} = V_{GT} + I_{GT}R_G$ (Eq. 15-1)
$V_{in} = 1.5\text{ V} + (15\text{ mA})(2.2\text{ k}\Omega)$
$V_{in} = 34.5$ V

$V_{CC} = I_H R + 0.7$ V (Eq. 15-2)
$V_{CC} = (10\text{ mA})(47\ \Omega) + 0.7$ V
$V_{CC} = 1.17$ V

Answer: The input voltage required to turn on the SCR is 34.5 V, and the supply voltage required to turn the SCR off is 1.17 V.

15-10. *Given:*

$V_{GT} = 2$ V
$I_{GT} = 8$ mA
$I_H = 2$ mA
$V_{CC} = 12$ V
$R_G = 6.6$ kΩ
$R = 141$ Ω

Solution:

$V_{in} = V_{GT} + I_{GT}R_G$ (Eq. 15-1)
$V_{in} = 2\text{ V} + (8\text{ mA})(6.6\text{ k}\Omega)$
$V_{in} = 54.8$ V

Answer: The input voltage required to turn on the SCR is 54.8 V.

15-11. *Given:*

$R = 750$ Ω
$R_1 = 3.3$ kΩ
$R_2 = 6.8$ kΩ
$C = 4.7$ μF

Solution:

$RC = R_{th(\text{cap})}C$
$RC = (2.54\text{ k}\Omega)(4.7\ \mu\text{F})$
$RC = 11.9$ msec

$R_{th} = R \| R_1$
$R_{th} = 750 \| 3.3$ kΩ
$R_{th} = 611$ Ω

Answer: The charging time constant is 11.9 ms. and the Thevenin resistance is 611 Ω.

15-12. *Given:*

$R_1 = 1$ kΩ
$R_2 = 4.6$ kΩ
$C = 0.47$ μF

Solution:

$X_C = 1/(2\pi fC)$
$X_C = 1/(2\pi(60\text{ Hz})(0.47\ \mu\text{F})$
$X_C = 5644$ Ω

$$Z = \sqrt{R^2 + X^2}$$
$$Z = \sqrt{5.6k\Omega^2 + 5.644k\Omega^2}$$
$$Z = 7.95\ k\Omega$$

$$\theta_Z = \angle -\arctan\left(\frac{X_C}{R}\right)$$

$$\theta_Z = \angle -\arctan\left(\frac{5.644k\Omega}{5.6k\Omega}\right)$$

$$\theta_Z = \angle -45°$$

$$I_C \angle\theta = \frac{V_{in}}{Z_T \angle -\arctan\left(\frac{X_C}{R}\right)}$$

$$I_C \angle\theta = \frac{120\ V \angle 0°}{7.95k\Omega \angle -45°}$$

$$I_C \angle\theta = 15\ mA \angle -45°$$

$$V_C = \left(I_C \angle\theta\right)\left(X_C \angle -90°\right)$$

$$V_C = (15\ mA \angle -45°)(5644\ \Omega \angle -90°)$$

$$V_C = 85\ V \angle -45°)$$

$$\theta^{\circ}_{cond} = 180° - \theta^{\circ}_{firing}$$
$$\theta^{\circ}_{cond} = 180° - 45°$$

$\theta^{\circ}_{cond} = 135$

Answer: The firing angle is 45°, the conduction angle is 135°, and the voltage across the capacitor is 85 Vac.

15-13. *Given:*

$R_1 = 1\ k\Omega$
$R_2 = 50\ k\Omega$ pot
$C = 0.47\ \mu F$

Solution: Perform the following calculations with an R value of 1 kΩ and 51 kΩ.

$X_C = 1/(2\pi fC)$
$X_C = 1/(2\pi(60\ Hz)(0.47\ \mu F)$
$X_C = 5644\ \Omega$

$$Z = \sqrt{R^2 + X^2}$$
$$Z = \sqrt{1\ k\Omega^2 + 5.644\ k\Omega^2}$$
$$Z = 5.732\ k\Omega$$

$$\theta_Z = \angle -\arctan\left(\frac{X_C}{R}\right)$$

$$\theta_Z = \angle -\arctan\left(\frac{5.644\ k\Omega}{1\ k\Omega}\right)$$

$$\theta_Z = \angle -80°$$

$$I_C \angle \theta = \frac{V_{in}}{Z_T \angle -\arctan\left(\frac{X_C}{R}\right)}$$

$$I_C \angle \theta = \frac{120\ V \angle 0°}{5.732\ k\Omega \angle -80°}$$

$$I_C \angle \theta = 20.9\ mA \angle 80°$$

$$V_C = (I_C \angle \theta)(X_C \angle -90°)$$
$$V_C = (20.9\ mA \angle 80°)(5644\ \Omega \angle -90°)$$
$$V_C = 118\ V \angle -10°$$

Answer: The minimum firing angle is 10°, and the maximum firing angle is 83.7°.

15-14. *Given:*

$R_1 = 1\ k\Omega$
$R_2 = 50\ k\Omega$ pot
$C = 0.47\ \mu F$

Solution: Perform the following calculations with an R value of 1 kΩ and 51 kΩ.

$X_C = 1/(2\pi fC)$
$X_C = 1/(2\pi(60\ Hz))(0.47\ \mu F)$
$X_C = 5644\ \Omega$

$$Z = \sqrt{R^2 + X^2}$$
$$Z = \sqrt{1\ k\Omega^2 + 5.644\ k\Omega^2}$$
$$Z = 5.732\ k\Omega$$

$$\theta_Z = \angle -\arctan\left(\frac{X_C}{R}\right)$$

$$\theta_Z = \angle -\arctan\left(\frac{5.644\ k\Omega}{1\ k\Omega}\right)$$

$$\theta_Z = \angle -80°$$

$$I_C \angle \theta = \frac{V_{in}}{Z_T \angle -\arctan\left(\frac{X_C}{R}\right)}$$

$$I_C \angle \theta = \frac{120\ V \angle 0°}{5.732\ k\Omega \angle -80°}$$

$$I_C \angle \theta = 20.9\ mA \angle 80°$$

$$V_C = (I_C \angle \theta)(X_C \angle -90°)$$
$$V_C = (20.9\ mA \angle 80°)(5644\ \Omega \angle -90°)$$
$$V_C = 118\ V \angle -10°$$

$\theta^{\circ}_{cond} = 180° - \theta^{\circ}_{firing}$
$\theta^{\circ}_{cond} = 180° - 10°$
$\theta^{\circ}_{cond} = 170°$

Answer: The minimum conduction angle is 170°, and the maximum conduction angle is 96.3°.

15-15. *Given:*

$V_{GT} = 0.8\ V$
$I_{GT} = 200\ \mu A$
$V_Z = 10\ V$

Solution:

$V_{CC} = V_Z + V_{GT}$ (Eq. 15-3)
$V_{CC} = 10\ V + 0.8\ V$
$V_{CC} = 10.8\ V$

Answer: The voltage needed to trigger the crowbar is 10.8 V.

15-16. *Given:*

$V_{GT} = 1.5\ V$
$I_{GT} = 200\ \mu A$
$V_Z = 10\ V \pm 10\%$

Solution:

$V_{Z(\max)} = V_Z + 0.1(V_Z)$
$V_{Z(\max)} = 10\ V + 0.1(10\ V)$
$V_{Z(\max)} = 11\ V$

$V_{CC} = V_Z + V_{GT}$ (Eq. 15-3)
$V_{CC} = 11\ V + 1.5\ V$
$V_{CC} = 12.5\ V$

Answer: The voltage needed to trigger the crowbar is 12.5 V.

15-17. *Given:*

$V_{GT} = 0.8\ V$
$I_{GT} = 200\ \mu A$
$V_Z = 12\ V$

Solution:

$V_{\text{trig}} = V_Z + V_{GT}$ (Eq. 15-3)
$V_{\text{trig}} = 12\ V + 0.8\ V$
$V_{\text{trig}} = 12.8\ V$

Answer: The SCR will trigger at 12.8 V.

15-18. *Given:*

$V_{GT} = 0.8\ V$
$I_{GT} = 200\ \mu A$
$V_Z = 12\ V$

Solution:

$V_{CC} = V_Z + V_{GT}$ (Eq. 15-3)
$V_{CC} = 12\ V + 0.8\ V$
$V_{CC} = 12.8\ V$

Answer: The voltage needed to trigger the crowbar is 12.8 V.

15-19. *Given:*

$V_B = 20\ V$
$V_{GT} = 2.5\ V$

Solution: Ignore the gate current in the triac. Then

$V_C = V_B + V_{GT}$
$V_C = 20\ V + 2.5\ V$
$V_C = 22.5\ V$

Answer: The capacitor voltage required to turn on the triac is 22.5 V.

15-20. *Given:*

$V_{CC} = 100$ V
$R = 15\ \Omega$

Solution: Ideally, when the triac is conducting, the voltage drop across it is 0 V.

$I = V_{CC}/R$
$I = 100\ \text{V}/15\ \Omega$
$I = 6.67$ A

Answer: The load current is 6.67 A.

15-21. *Given:*

$V_B = 28$ V
$V_{GT} = 2.5$ V

Solution: Ignore the current through the diac and triac. Then

$V_C = V_B + V_{GT}$
$V_C = 28\ \text{V} + 2.5\ \text{V}$
$V_C = 30.5$ V

Answer: The capacitor voltage required to turn on the triac is 30.5 V.

15-22. *Given:*

$V_{CC} = 15$ V
$R_2 = 1\ \text{k}\Omega$
$R_3 = 2\text{V}$

Solution:

$V_{\text{gate}} = [R_3/(R_2 + R_3)]\text{V}_{CC}$ (Voltage divider formula)
$V_{\text{gate}} = [2\ \text{k}\Omega/(1\ \text{k}\Omega + 2\ \text{k}\Omega)]15\ \text{V}$
$V_{\text{gate}} = 10$ V

$V_{\text{anode}} = V_{Trig} + 0.7$ V
$V_{\text{anode}} = 10\ \text{V} + 0.7$
$V_{\text{anode}} = 10.7$ V

Answer: The gate trigger voltage is 10 V and the anode is 10.7 V.

15-23. *Given:*

$V_{CC} = 15$ V
$V_{\text{gate}} = 10$ V
$V_{\text{anode}} = 10.7$ V

Solution:

$V_{R4} = V_{\text{anode}} - 0.7$ V
$V_{R4} = 10.7\ \text{V} - 0.7$
$V_{R4} = 10$ V

Answer: The peak voltage across $R_4 = 10$ V.

15-24. *Answer:* The output waveform will be a sawtooth waveform from 0 V to 10.7 V.

CRITICAL THINKING

15-25. *Answer:* The breakover voltage of the diode, which is 10 V.

15-26. *Answer:* The breakover voltage of the diode, which is 10 V.

15-27. *Given:*

$R_1 = 0$ to $50\ \text{k}\Omega$
$R_2 = 1\ \text{k}\Omega$
$C = 0.1\ \mu\text{F}$
$T = 20\%(RC)$

Solution:

$R_{\max} = R_2 + R_{1\ (\max)}$
$R_{\max} = 1\ \text{k}\Omega + 50\ \text{k}\Omega$
$R_{\max} = 51\ \text{k}\Omega$

$R_{\min} = R_2 + R_{1\ (\min)}$
$R_{\min} = 1\ \text{k}\Omega + 0\ \text{k}\Omega$
$R_{\min} = 1\ \text{k}\Omega$

$RC_{\max} = R_{\max}C$
$RC_{\max} = (51\ \text{k}\Omega)(0.1\ \mu\text{F})$
$RC_{\max} = 5.1$ ms

$RC_{\min} = R_{\max}C$
$RC_{\min} = (1\ \text{k}\Omega)(0.1\ \mu\text{F})$
$RC_{\min} = 0.1$ msec

$T_{\max} = 0.2(RC_{\max})$
$T_{\max} = 0.2(5.1\ \text{ms})$
$T_{\max} = 1.02$ ms

$T_{\min} = 0.2(RC_{\min})$
$T_{\min} = 0.2(0.1\ \text{ms})$
$T_{\min} = 0.02$ ms

$f_{\max} = 1/T_{\min}$
$f_{\max} = 1/0.02$ ms
$f_{\max} = 50$ kHz

$f_{\min} = 1/T_{\max}$
$f_{\min} = 1/1.02$ ms
$f_{\min} = 980$ Hz

Answer: The maximum frequency is 50 kHz, and the minimum is 980 Hz.

15-28. *Given:*

$R = 100\ \Omega$
$V_{CC} = 15$ V

Solution: In a dark room the SCR is off and the output voltage is 15 V. Once the SCR fires, its voltage drops to 0.7 V.

$I = (V_{CC} - 0.7\ \text{V})/R$
$I = (15\ \text{V} - 0.7\ \text{V})/100\ \Omega$
$I = 143$ mA

Answer: The output voltage when it is dark is 20 V and when it is light is 0.7 V, and the current through the resistor is 143 mA when it is light.

15-29. *Answer:*

Trouble 1: Since there is voltage at *D* and not at *E*, the wire connecting the two is open.

Trouble 2: No supply voltage.

Trouble 3: Since there is voltage at *B* and not at *C*, the transformer is the problem.

Trouble 4: Since there is voltage at *A* and not at *B*, the fuse is open.

15-30. *Answer:*

Trouble 5: Since there is an overvoltage and the crowbar is off, the problem is the crowbar.

Trouble 6: Since there is voltage at *C* and not at *D* and the load resistor is not shorted, the rectifier is the problem.

Trouble 7: Since there is voltage at *E* and not at *F*, the wire connecting the two is open.

Trouble 8: Since there is voltage at *A* and not at *B*, the fuse is open.

Chapter 16 Frequency Effects

SELF-TEST

1. a	**6. c**	**11. c**	**16. a**
2. b	**7. b**	**12. c**	**17. d**
3. c	**8. c**	**13. d**	**18. b**
4. c	**9. c**	**14. a**	**19. c**
5. b	**10. d**	**15. c**	**20. a**

JOB INTERVIEW QUESTIONS

1. Too much stray-wiring capacitance. Shorten the leads as much as possible.
2. With a sine wave, find the frequency at which the voltage gain is down 3 dB. With a square wave, use the step-response method.
5. Some oscilloscopes (with plug-in vertical preamps) specify the risetime of the main frame. A risetime of 0.7 ns converts to a bandwidth of 50 MHz.
6. Use a step voltage and measure the risetime of the output signal.
8. Maximum power transfer.
9. dBm is referenced to 1 mW, whereas dB is not referenced to any standard.
10. Because it amplifies down to 0 Hz, which is the frequency of a dc signal.
11. Semilogarithmic
12. It is a computer program that provides electronic circuit simulation. It is used to build, test, and analyze simulated circuits.

PROBLEMS

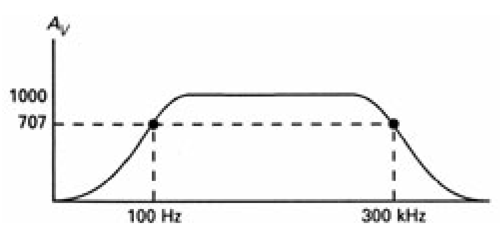
16-1. *Given:*

$A_{v(mid)} = 1000$
$f_1 = 100$ Hz
$f_2 = 100$ kHz

Solution:

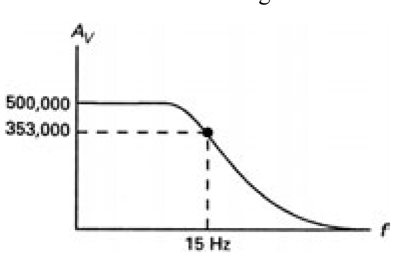
$A_{v(20K)} = A_{mid}/[\sqrt{1+(f_1/f)^2}]$ (Eq. 16-3)
$A_{v(20K)} = 1000/[\sqrt{1+(100\text{ Hz}/20\text{ Hz})^2}]$
$A_{v(20K)} = 196$
$A_{v(300K)} = A_{mid}/[\sqrt{1+(f/f_2)^2}]$ (Eq. 16-3)
$A_{v(300K)} = 1000/[\sqrt{1+(300\text{ kHz}/100\text{ kHz})^2}]$
$A_{v(300K)} = 316$

Answer: The frequency response looks like the figure below; the gain at 20 Hz is 196, and at 300 kHz is 316.



Frequency response for Prob. 16-1.

16-2. *Answer:* See the figure below.



Frequency response for Prob. 16-2.

16-3. *Given:*

$A_{v(mid)} = 200$
$f_2 = 10$ kHz
$f = 100$ kHz, 200 kHz, 500 kHz, 1 MHz

Solution: Substitute in the appropriate value for f.

$$A_v = \frac{A_{v(mid)}}{\sqrt{1+\left(\frac{f}{f_2}\right)^2}}$$

$$A_v = \frac{200}{\sqrt{1+\left(\frac{100\text{ kHz}}{10\text{ kHz}}\right)^2}}$$

$A_v = 19.9$

Answer: $A_v = 19.9$ at 100 kHz, $A_v = 9.98$ at 200 kHz, $A_v = 4$ at 500 kHz, $A_v = 2$ at 1 MHz.

16-4. *Given:* $A_P = 5, 10, 20, 40$

Solution:

$A_{P(dB)} = 10 \log A_P$
$A_{P(dB)} = 10 \log(5)$
$A_{P(dB)} = 7$ dB

$A_{P(dB)} = 10 \log A_P$
$A_{P(dB)} = 10 \log(10)$
$A_{P(dB)} = 10$ dB

$A_{P(dB)} = 10 \log A_P$
$A_{P(dB)} = 10 \log(20)$
$A_{P(dB)} = 13$ dB

$A_{P(dB)} = 10 \log A_P$
$A_{P(dB)} = 10 \log(40)$
$A_{P(dB)} = 16$ dB

Answer: The decibel power gain is 7 dB at a power gain of 5, 10 dB at 10, 13 dB at 20, and 16 dB at 40.

16-5. *Given:* $A_P = 0.4, 0.2, 0.1, 0.05$

Solution:

$A_{P(dB)} = 10 \log A_P$ (Eq. 16-8)
$A_{P(dB)} = 10 \log(0.4)$
$A_{P(dB)} = -3.98$

$A_{P(dB)} = 10 \log A_P$ (Eq. 16-8)
$A_{P(dB)} = 10 \log(0.2)$
$A_{P(dB)} = -6.99$

$A_{P(dB)} = 10 \log A_P$ (Eq. 16-8)
$A_{P(dB)} = 10 \log(0.1)$
$A_{P(dB)} = -10$

$A_{P(dB)} = 10 \log A_P$ (Eq. 16-8)
$A_{P(dB)} = 10 \log(0.05)$
$A_{P(dB)} = -13$

Answer: The decibel power gain is –3.98 at a power gain of 0.4, –6.99 at 0.2, –10 at 0.1, and –13 at 0.05.

16-6. *Given:* $A_P = 2, 20, 200, 2000$

Solution:

$A_{P(dB)} = 10 \log A_P$ (Eq. 16-8)
$A_{P(dB)} = 10 \log(2)$
$A_{P(dB)} = 3$ dB

$A_{P(dB)} = 10 \log A_P$ (Eq. 16-8)
$A_{P(dB)} = 10 \log(20)$
$A_{P(dB)} = 13$ dB

$A_{P(\text{dB})} = 10 \log A_P$ (Eq. 16-8)
$A_{P(\text{dB})} = 10 \log(200)$
$A_{P(\text{dB})} = 23$ dB

$A_{P(\text{dB})} = 10 \log A_P$ (Eq. 16-8)
$A_{P(\text{dB})} = 10 \log(2000)$
$A_{P(\text{dB})} = 33$ dB

Answer: The decibel power gain is 3 dB at a power gain of 2, 13 dB at 20, 23 dB at 200, and 33 dB at 2000.

16-7. *Given:* $A_P = 0.4, 0.04, 0.004$

Solution:

$A_{P(\text{dB})} = 10 \log A_P$ (Eq. 16-8)
$A_{P(\text{dB})} = 10 \log(0.4)$
$A_{P(\text{dB})} = -3.98$

$A_{P(\text{dB})} = 10 \log A_P$ (Eq. 16-8)
$A_{P(\text{dB})} = 10 \log(0.04)$
$A_{P(\text{dB})} = -13.98$

$A_{P(\text{dB})} = 10 \log A_P$ (Eq. 16-8)
$A_{P(\text{dB})} = 10 \log(0.004)$
$A_{P(\text{dB})} = -23.98$

Answer: The decibel power gain is –3.98 dB at a power gain of 0.4, –13.98 dB at 0.04, and –23.98 dB at 0.004.

16-8. *Given:*

$A_{v1} = 200$
$A_{v2} = 100$

Solution:

$A_v = A_{v1}A_{v2}$ (Eq. 16-10)
$A_v = (200)(100)$
$A_v = 20{,}000$

$A_{v(\text{dB})} = 20 \log A_v$ (Eq. 16-8)
$A_{v(\text{dB})} = 20 \log(20{,}000)$
$A_{v(\text{dB})} = 86$ dB

Answer: The voltage gain is 20,000, and the decibel voltage gain is 86 dB.

16-9. *Given:*

$A_{v1} = 200$
$A_{v2} = 100$

Solution:

$A_{v1(\text{dB})} = 20 \log A_{v1}$ (Eq. 16-8)
$A_{v1(\text{dB})} = 20 \log(200)$
$A_{v1(\text{dB})} = 46$ dB

$A_{v2(\text{dB})} = 20 \log A_{v2}$ (Eq. 16-8)
$A_{v2(\text{dB})} = 20 \log(100)$
$A_{v2(\text{dB})} = 40$ dB

Answer: The decibel voltage gain for stage 1 is 46 dB, and stage 2 is 40 dB.

16-10. *Given:*

$A_{v1(\text{dB})} = 30$ dB
$A_{v2(\text{dB})} = 52$ dB

Solution:

$A_{v(\text{dB})} = A_{v1(\text{dB})} + A_{v2(\text{dB})}$ (Eq. 16-11)
$A_{v(\text{dB})} = 30 \text{ dB} + 52 \text{ dB}$
$A_{v(\text{dB})} = 82$ dB

$A_v = \text{antilog}(A_{v(\text{dB})}/20)$ (Eq. 16-15)
$A_v = \text{antilog}(82 \text{ dB}/20)$
$A_v = 12{,}589$

Answer: The decibel voltage gain is 82, and the voltage gain is 12,589.

16-11. *Given:*

$A_{v1(\text{dB})} = 30$ dB
$A_{v2(\text{dB})} = 52$ dB

Solution:

$A_{v1} = \text{antilog}(A_{v1(\text{dB})}/20)$ (Eq. 16-15)
$A_{v1} = \text{antilog}(30 \text{ dB}/20)$
$A_{v1} = 31.6$

$A_{v2} = \text{antilog}(A_{v2(\text{dB})}/20)$ (Eq. 16-15)
$A_{v2} = \text{antilog}(52 \text{ dB}/20)$
$A_{v2} = 398$

Answer: The voltage gain of the first stage is 31.6, and the second stage is 398.

16-12. *Given:* $A_v = 100{,}000$

Solution:

$A_{v(\text{dB})} = 20 \log A_v$ (Eq. 16-9)
$A_{v(\text{dB})} = 20 \log(100{,}000)$
$A_{v(\text{dB})} = 100$

Answer: The decibel voltage gain is 100 dB.

16-13. *Given:* $A_{\text{dB}} = 34$ dB

Solution:

$A_v = \text{antilog}(A_{v(\text{dB})}/20)$ (Eq. 16-15)
$A_v = \text{antilog}(34 \text{ dB}/20)$
$A_v = 50.1$

Answer: The voltage gain is 50.1.

16-14. *Given:*

$A_{v1} = 25.8$
$A_{v2} = 117$

Solution:

$A_{v1(\text{dB})} = 20 \log A_{v1}$ (Eq. 16-9)
$A_{v1(\text{dB})} = 20 \log(25.8)$
$A_{v1(\text{dB})} = 28.2$ dB

$A_{v2(\text{dB})} = 20 \log A_{v2}$ (Eq. 16-9)
$A_{v2(\text{dB})} = 20 \log(117)$
$A_{v2(\text{dB})} = 41.4$ dB

$A_{v(\text{dB})} = A_{v1(\text{dB})} + A_{v2(\text{dB})}$ (Eq. 16-11)
$A_{v(\text{dB})} = 28.2 \text{ dB} + 41.4 \text{ dB}$
$A_{v(\text{dB})} = 69.6$ dB

Answer: The decibel voltage gain for the first stage is 28.2 dB, the second stage is 41.4 dB, and overall is 69.6 dB.

16-15. *Given:*

$A_{P1(\text{dB})} = 23$ dB
$A_{P2(\text{dB})} = 18$ dB

Solution:

$A_{P1(\text{dB})} = A_{v1(\text{dB})} = 23$ dB
$A_{P2(\text{dB})} = A_{v2(\text{dB})} = 18$ dB

$A_{v(\text{dB})} = A_{v1(\text{dB})} + A_{v2(\text{dB})}$ (Eq. 16-11)
$A_{v(\text{dB})} = 23 \text{ dB} + 18 \text{ dB}$
$A_{v(\text{dB})} = 41$ dB

Answer: The total decibel voltage gain is 41 dB, the first-stage decibel voltage gain is 23 dB, and the second stage voltage gain is 18 dB.

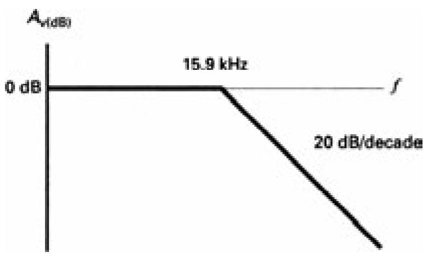
16-23. *Given:*

$C = 1000$ pF
$R = 10$ kΩ

Solution:

$f_2 = 1/(2\pi RC)$
$f_2 = 1/[2\pi(10\text{ k}\Omega)(1000\text{ pF})]$
$f_2 = 15.9$ kHz

Answer: See figure below.



Ideal Bode plot for Prob. 16-23.

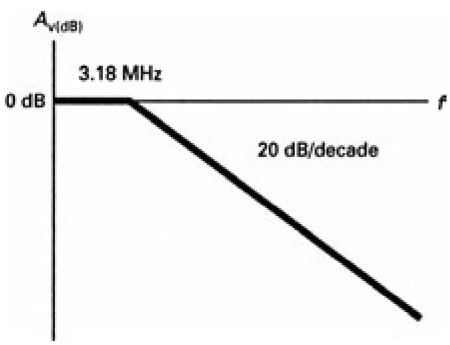
16-24. *Given:*

$R = 1$ kΩ
$C = 50$ pF

Solution:

$f_2 = 1/(2\pi RC)$
$f_2 = 1/[2\pi(1\text{ k}\Omega)(50\text{ pF})]$
$f_2 = 3.18$ MHz

Answer: See figure below.



Ideal Bode plot for Prob. 16-24.

16-25. *Given:*

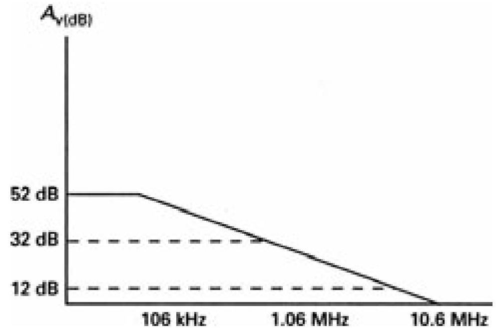
$R = 15$ kΩ
$C = 100$ pF
$A_{v(mid)} = 400$

Solution:

$f_2 = 1/(2\pi RC)$
$f_2 = 1/[2\pi(15\text{ k}\Omega)(100\text{ pF})]$
$f_2 = 106$ kHz

$A_{v(dB)} = 20 \log A_v$ (Eq. 16-9)
$A_{v(dB)} = 20 \log(400)$
$A_{v(dB)} = 52$ dB

Answer: See figure at top of next column.



Ideal Bode plot for Prob. 16-25.

16-26. *Given:*

$C = 5$ pF
$A_v = 200{,}000$

Solution:

$C_{in} = C(A_v + 1)$ (Eq. 16-26)
$C_{in} = 5\text{ pF}(200{,}000 + 1)$
$C_{in} = 1\ \mu$F

Answer: The Miller input capacitance is 1 μF.

16-27. *Given:*

$C = 15$ pF
$A_v = 250{,}000$
$R_L = 10$ kΩ
$R_{in} = 1$ kΩ

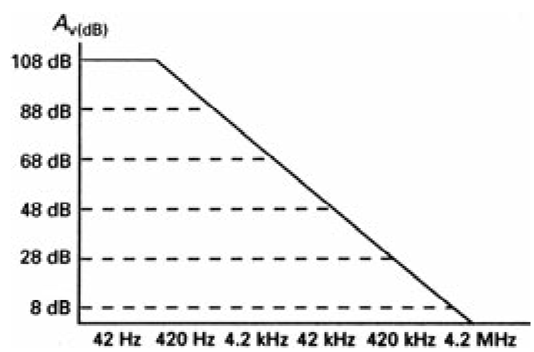
Solution:

$C_{in} = C(A_v + 1)$ (Eq. 16-26)
$C_{in} = 15\text{ pF}(250{,}000 + 1)$
$C_{in} = 3.75\ \mu$F

$f_2 = 1/(2\pi RC)$
$f_2 = 1/[2\pi(1\text{ k}\Omega)(3.75\ \mu\text{F})]$
$f_2 = 42$ kHz

$A_{v(dB)} = 20 \log A_v$ (Eq. 16-9)
$A_{v(dB)} = 20 \log(250{,}000)$
$A_{v(dB)} = 108$ dB

Answer: See figure below.



Ideal Bode plot for Prob. 16-27.

16-28. *Given:*

$C = 50$ pF
$A_v = 200{,}000$

Solution:

$C_{in} = C(A_v + 1)$ (Eq. 16-26)
$C_{in} = 50\text{ pF}(200{,}000 + 1)$
$C_{in} = 10\ \mu$F

Answer: The Miller input capacitance is 10 μF.

16-29. *Given:*

$C = 100$ pF
$A_v = 150{,}000$
$R_L = 10$ kΩ
$R_{in} = 1$ kΩ

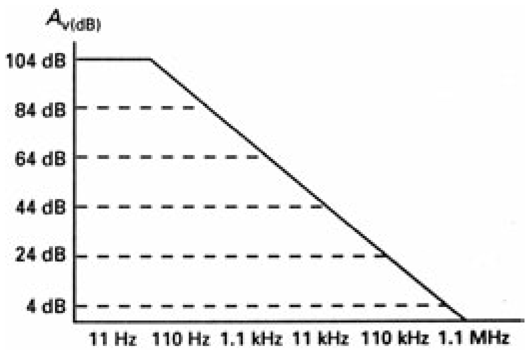
Solution:

$C_{in} = C(A_v + 1)$ (Eq. 16-26)
$C_{in} = 100\text{ pF}(150{,}000 + 1)$
$C_{in} = 15\ \mu\text{F}$

$f_2 = 1/(2\pi RC)$
$f_2 = 1/[2\pi(1\text{ k}\Omega)(15\ \mu\text{F})]$
$f_2 = 11$ Hz

$A_{v(dB)} = 20 \log A_v$ (Eq. 16-9)
$A_{v(dB)} = 20 \log(150{,}000)$
$A_{v(dB)} = 104$ dB

Answer: See figure below.



Ideal Bode plot for Prob. 16-29.

16-30. *Given:*

$T_R = 10\ \mu$s

Solution:

$f_2 = 0.35/T_R$ (Eq. 16-29)
$f_2 = 0.35/10\ \mu\text{s}$
$f_2 = 35$ kHz

Answer: The upper cutoff frequency is 35 kHz.

16-31. *Given:*

$T_R = 0.25\ \mu$s

Solution:

$f_2 = 0.35/T_R$ (Eq. 16-29)
$f_2 = 0.35/0.25\ \mu\text{s}$
$f_2 = 1.4$ MHz

Answer: The bandwidth is 1.4 MHz.

16-32. *Given:*

$f_2 = 100$ kHz

Solution:

$f_2 = 0.35/T_R$ (Eq. 16-29)
$T_R = 0.35/f_2$
$T_R = 0.35/100\text{ kHz}$
$T_R = 3.5\ \mu$s

Answer: The risetime is 3.5 μs.

16-33. *Given:*

$C = 1\ \mu$F
$R = 50\ \Omega$

Solution:

$R_{in} = Z_{in(Stage)}$
$R_{in} = R_1 \parallel R_2 \parallel \beta r_e'$
$R_{in} = 717\ \Omega$

$f_{C1} = 1/(2\pi R_{in} C)$
$f_{C1} = 1/[2\pi(717\ \Omega)(1\ \mu\text{F})]$
$f_{C1} = 222$ Hz

Answer: The lower cutoff frequency for the base coupling circuit is 222 Hz.

16-34. *Given:*

$C = 4.7\ \mu$F
$R_C = 3.6$ kΩ
$R_L = 10$ kΩ

Solution:

$R = R_C + R_L$
$R = 36\text{ k}\Omega + 10\text{ k}\Omega$
$R = 13.6$ kΩ

$f_{C1} = 1/(2\pi RC)$
$f_{C1} = 1/[2\pi(13.6\text{ k}\Omega)(4.7\ \mu\text{F})]$
$f_{C1} = 2.49$ Hz

Answer: The lower cutoff frequency for the collector coupling circuit is 2.49 Hz.

16-35. *Given:*

$C = 25\ \mu$F
$R_C = 3.6$ kΩ
$R_L = 10$ kΩ

Solution:

$f_{C1} = 1/(2\pi Z_{out} C)$
$f_{C1} = 1/[2\pi(22.4\ \Omega)(25\ \mu\text{F})]$
$f_{C1} = 284$ Hz

Answer: The lower cutoff frequency for the emitter bypass circuit is 284 Hz.

16-36. *Given:*

$C_c' = 2$ pF
$C_e' = 10$ pF
$C_{Stray}' = 5$ pF
$R_1 = 10$ kΩ
$R_2 = 2.2$ kΩ
$R_C = 3.6$ kΩ
$R_L = 10$ kΩ
$R_G = 50$ kΩ
$\beta = 200$

Solution:

$r_g = R_G \| R_1 \| R_2$
$r_g = 50\ \Omega \| 10\text{ k}\Omega \| 2.2\text{ k}\Omega$
$r_g = 48\ \Omega$

$C_{in(m)} = 236$ pF
$C = C_{in(m)} + C_e' = 246$ pF

Base

$f_2 = 1/(2\pi r_g C)$
$f_2 = 1/[2\pi(48\ \Omega)(246\text{ pF})]$
$f_2 = 13.5$ MHz

Collector

$C = C_e' + C_{Stray} = 7$ pF
$C_{out(m)} = 2$ pF

$R = R_C + R_L$
$R = 3.6\text{ k}\Omega + 10\text{ k}\Omega$
$R = 13.6$ kΩ

$f_2 = 1/(2\pi RC)$
$f_2 = 1/[2\pi(13.6\ \Omega)(1.3\text{ pF})]$
$f_2 = 8.59$ MHz

Answer: The high cutoff frequency for the base is 13.5 MHz and the collector is 8.59 MHz.

16-37. *Given:*

$g_m = 16.5$ mS
$C_{iSS} = 30$ pF
$C_{oSS} = 20$ pF
$C_{rSS} = 5$ pF

Solution:

$C_{gd} = C_{rSS} = 5$ pF
$C_{gS} = C_{iSS} - C_{rSS}$
$C_{gS} = 30$ pF $- 5$ pF
$C_{gS} = 25$ pF

$C_{dS} = C_{oSS} - C_{rSS}$
$C_{dS} = 20$ pF $- 5$ pF
$C_{dS} = 15$ pF

Answer: $C_{gS} = 25$ pF, $C_{gd} = C_{rSS} = 5$ pF, $C_{dS} = 15$ pF.

16-38. *Given:*

$R_1 = 2$ MΩ
$R_2 = 1$ MΩ
$R_D = 1$ kΩ
$R_L = 10$ kΩ
$R_G = 50$ Ω
$C_{in} = 0.01$ μF
$C_{out} = 1$ μF

Solution:

$R_{in} = Z_{in(Stage)}$
$R_{in} = R_1 \| R_2$
$R_{in} = 667$ kΩ

$f_{C1} = 1/(2\pi R_{in}C)$
$f_{C1} = 1/[2\pi(667\ \text{k}\Omega)(0.01\ \mu\text{F})]$
$f_{C1} = 23.9$ Hz or 14.5 Hz

Answer: The dominant low cutoff frequency is 23.9 Hz.

16-39. *Given:*

$R_1 = 2$ MΩ
$R_2 = 1$ MΩ
$R_D = 1$ kΩ
$R_L = 10$ kΩ
$R_G = 50$ kΩ
$C_{gd} = 5$ pF (from Prob. 16-37.)
$C_{gS} = 25$ pF (from Prob. 16-37.)
$C_{dS} = 015$ pF (from Prob. 16-37.)

Solution:

$A_v = g_m r_d$
$A_v = (16.5\ \text{mS})(1\ \text{k}\Omega \| 10\ \text{k}\Omega)$
$A_v = 15$

$C_{in(m)} = C_{gd}(A_v + 1)$ (Eq. 16-40)
$C_{in(m)} = 5\ \text{pF}(15 + 1)$
$C_{in(m)} = 80$ pF
$C = C_{gS} + C_{in(m)}$
$C = 25$ pF $+ 80$ pF
$C = 105$ pF
$R = R_G \| R_1 \| R_2$
$R = 50\ \Omega \| 2\ \text{M}\Omega \| 1\ \text{M}\Omega$
$R = 50$ Ω

Gate

$f_2 = 1/(2\pi RC)$
$f_2 = 1/[2\pi(50\ \Omega)(105\ \text{pF})]$
$f_2 = 30.3$ MHz

Collector

$C_{out(M)} = C_{gd}[(A_v + 1)/A_v]$ (Eq. 16-41)
$C_{out(M)} = 5\ \text{pF}[(15 + 1)/15]$
$C_{out(M)} = 5.3$ pF
$C = C_{dS} + C_{out(m)}$
$C = 15$ pF $+ 5.3$ pF

Drain

$f_2 = 1/(2\pi RC)$
$f_2 = 1/[2\pi(909\ \Omega)(20.3\ \text{pF})]$
$f_2 = 8.61$ MHz

Answer: The high frequency cutoff for the gate is 30.3 MHz and the drain is 8.61 MHz.

CRITICAL THINKING

16-40. *Given:*

$f_2 = 100$ Hz
$A_{v(dB)} = 80$ dB

Solution:

$A_{v(mid)} = \text{antilog}(A_{v(dB)}/20)$ (Eq. 16-15)
$A_{v(mid)} = \text{antilog}(80\ \text{dB}/20)$
$A_{v(mid)} = 10{,}000$

$A_{v(20K)} = A_{v(mid)}/[\sqrt{1+(f/f_2)^2}\,]$ (Eq. 16-3)
$A_{v(20K)} = 10{,}000/[\sqrt{1+(20\ \text{kHz}/100\ \text{Hz})^2}\,]$
$A_{v(20K)} = 50$

$A_{v(dB)} = 20 \log A$ (Eq. 16-9)
$A_{v(dB)} = 20 \log(50)$
$A_{v(dB)} = 34$ dB

$A_{v(44.4K)} = A_{v(mid)}/[\sqrt{1+(f/f_2)^2}\,]$ (Eq. 16-3)
$A_{v(44.4K)} = 10{,}000/[\sqrt{1+(44.4\ \text{kHz}/100\ \text{Hz})^2}\,]$
$A_{v(44.4K)} = 22.5$

$A_{v(dB)} = 20 \log A_v$ (Eq. 16-9)
$A_{v(dB)} = 20 \log(22.5)$
$A_{v(dB)} = 27$ dB

Answer: The decibel voltage gain at 20 kHz is 34 dB, and at 44.4 kHz is 27 dB.

16-41. *Given:*

$f_2 = 100$ Hz
Second breakpoint is 10 kHz
$A_{v(mid)} = 120$ dB

Solution: Since the roll-off is 20 dB/decade at a frequency of 1 kHz (one decade above the cutoff frequency), the gain is 100 dB (20 dB less than the midband), and at 10 kHz the gain is 80 dB. From this point the roll-off increases to 40 dB/decade; thus at 100 kHz, the gain will be 40 dB.

Answer: The voltage gain at 100 kHz is 40 dB.

16-42. *Given:*

$V_{in} = 20$ mV
$A_{v(mid)} = 100$

Solution:

$V_{out(max)} = A_{v(mid)}V_{in}$
$V_{out(max)} = (100)(20\ \text{mV})$
$V_{out(max)} = 2$ V

At the 10% point = 0.1 $V_{out(max)}$
At the 10% point = 0.1(2 V)
At the 10% point = 0.2 V

At the 90% point = 0.9 $V_{out(max)}$
At the 90% point = 0.9(2 V)
At the 90% point = 1.8 V

Answer: The voltage at the 10% point is 0.2 V, and at the 90% point is 1.8 V.

16-43. *Given:*

$R = 4\ k\Omega$
$C = 50\ pF$

Solution:

$f_2 = 1/(2\pi RC)$
$f_2 = 1/[2\pi(4\ k\Omega)(50\ pF)]$
$f_2 = 796\ kHz$

$f_2 = 0.35/T_R$ (Eq. 16-29)
$T_R = 0.35/f_2$
$T_R = 0.35/796\ kHz$
$T_R = 0.44\ \mu s$

Answer: The risetime is 0.44 µs.

16-44. *Given:*

$f_2 = 1\ MHz$
$T_R = 1\ \mu s$

Solution:

$f_2 = 0.35/T_R$ (Eq. 16-29)
$f_2 = 0.35/1\ \mu s$
$f_2 = 350\ kHz$

Answer: The amplifier with the cutoff frequency of 1 MHz has the larger bandwidth.

Chapter 17 Differential Amplifiers

SELF-TEST

1. b	**7. b**	**13. c**	**19. b**
2. c	**8. a**	**14. a**	**20. c**
3. a	**9. d**	**15. a**	**21. a**
4. c	**10. a**	**16. b**	**22. c**
5. b	**11. c**	**17. d**	**23. c**
6. a	**12. b**	**18. c**	

JOB INTERVIEW QUESTIONS

6. Use a transistor as a current source instead of a tail resistor. It could be a regulator configuration or a current source.
9. A transistor acting as a current source.
11. Current sources and active loads.
12. Increased voltage gain and higher CMRR.
13. Trick question. You can't test a 741 with an ohmmeter.

PROBLEMS

17-1. *Given:*

$V_{CC} = 15\ V$
$V_{EE} = –15\ V$
$R_E = 270\ k\Omega$
$R_C = 180\ k\Omega$

Solution:

$I_T = –V_{EE}/R_E$
$I_T = –15\ V/270\ k\Omega$
$I_T = 55.6\ \mu A$

$I_E = 1/2\ I_T$
$I_E = 1/2\ (55.6\ \mu A)$
$I_E = 27.8\ \mu A$

$V_C = V_{CC} – (27.8\ \mu A)(180\ k\Omega)$
$V_C = 10\ V$

Answer: The tail current is 55.6 µA, the emitter is 27.8 µA, and the quiescent voltage is 10 V.

17-2. *Given:*

$V_{CC} = 15\ V$
$V_{EE} = –15\ V$
$R_E = 270\ k\Omega$
$R_C = 180\ k\Omega$

Solution:

$I_T = (– V_{EE} – V_{BE})/R_E$
$I_T = (–15\ V – 0.7\ V)/270\ k\Omega$
$I_T = 53\ \mu A$
$I_E = 1/2\ I_T$
$I_E = 1/2(53\ \mu A)$
$I_E = 26.5\ \mu A$
$V_C = V_{CC} – (26.5\ \mu A)(180\ k\Omega)$
$V_C = 10.2\ V$

Answer: The tail current is 53 µA, the emitter is 26.5 µA, and the quiescent voltage is 10.2 V.

17-3. *Given:*

$V_{CC} = 12\ V$
$V_{EE} = –12\ V$
$R_E = 200\ k\Omega$
$R_C = 200\ k\Omega$

Solution:

$I_T = (– V_{EE})/R_E$
$I_T = (– 12\ V)/200\ k\Omega$
$I_T = 60\ \mu A$

$I_E = 1/2\ I_T$
$I_E = 1/2(60\ \mu A)$
$I_E = 30\ \mu A$

Right Side

$V_C = V_{CC} – (30\ \mu A)(200\ k\Omega)$
$V_C = 6\ V$

Left Side

$V_C = 12\ V$

Answer: The tail current is 60 µA, the emitter is 30 µA, and the quiescent voltage is 6 V on the right side and 12 V on the left side.

17-4. *Given:*

$V_{CC} = 12\ V$
$V_{EE} = –12\ V$
$R_E = 200\ k\Omega$
$R_C = 200\ k\Omega$

Solution:

$I_T = (– V_{EE} – V_{BE})/R_E$
$I_T = (– 12\ V – 0.7\ V)/200\ k\Omega$
$I_T = 56.5\ \mu A$

$I_E = ½\ I_T$
$I_E = 1/2(56.5\ \mu A)$
$I_E = 28.3\ \mu A$

Right Side

$V_C = V_{CC} – (28.3\ \mu A)(200\ k\Omega)$
$V_C = 6.35\ V$

Left Side

$V_C = 12\ V$

Answer: The tail current is 56.5 µA, the emitter is 28.3 µA, and the quiescent voltage is 6.35 V on the right side and 12 V on the left side.

17-5. *Given:*

$V_{CC} = 15$ V
$V_{EE} = -15$ V
$R_E = 68$ kΩ
$R_C = 47$ kΩ
$\beta = 275$
$v_1 = 2.5$ mV

Solution:

$I_T = (-V_{EE}/R_E)$ (Eq. 17-5)
$I_T = (-15\text{ V})/68\text{ k}\Omega$
$I_T = 220.6\ \mu$A

$I_E = 1/2\ I_T$ (Eq. 17-6)
$I_E = 1/2\ (220.6\ \mu\text{A})$
$I_E = 110.3\ \mu$A

$r'_e = 25\text{ mV}/I_E$ (Eq. 9-10)
$r'_e = 25\text{ mV}/110.3\ \mu\text{A}$
$r'_e = 226.7\ \Omega$

$A_v = R_C/r'_e$ (Eq. 17-10)
$A_v = 47\text{ k}\Omega/226.7\ \Omega$
$A_v = 207.3$

$v_{out} = A_v(v_1 - v_2)$ (Eq. 17-2)
$v_{out} = 207.3(2.5\text{ mV} - 0)$
$v_{out} = 518$ mV

$z_{in} = 2\beta r'_e$ (Eq. 17-11)
$z_{in} = 2(275)(226.7\ \Omega)$
$z_{in} = 125$ kΩ

Answer: The output voltage is 518 mV, and the input impedance is 125 kΩ.

17-6. *Given:*

$V_{CC} = 15$ V
$V_{EE} = -15$ V
$R_E = 68$ kΩ
$R_C = 47$ kΩ
$\beta = 275$
$v_1 = 2.5$ mV

Solution:

$I_T = (-V_{EE} - V_{BE})/R_E$ (Eq. 17-5)
$I_T = (-15\text{ V} - 0.7\text{ V})/68\text{ k}\Omega$
$I_T = 210.3\ \mu$A

$I_E = 1/2\ I_T$ (Eq. 17-6)
$I_E = 1/2(210.3\ \mu\text{A})$
$I_E = 105.2\ \mu$A

$r'_e = 25\text{ mV}/I_E$ (Eq. 9-10)
$r'_e = 25\text{ mV}/105.2\ \mu\text{A}$
$r'_e = 237.6\ \Omega$

$A_v = R_C/r'_e$ (Eq. 17-10)
$A_v = 47\text{ k}\Omega/237.6\ \Omega$
$A_v = 197.8$

$v_{out} = A_v(v_1 - v_2)$ (Eq. 17-2)
$v_{out} = 197.8(2.5\text{ mV} - 0)$
$v_{out} = 494$ mV

$z_{in} = 2\beta r'_e$ (Eq. 17-11)
$z_{in} = 2(494)(237.6\ \Omega)$
$z_{in} = 131$ kΩ

Answer: The output voltage is 494 mV, and the input impedance is 131 kΩ.

17-7. *Given:*

$V_{CC} = 15$ V
$V_{EE} = -15$ V
$R_E = 68$ kΩ
$R_C = 47$ kΩ
$\beta = 275$
$v_1 = 0$ mV
$v_1 = 1$ mV

Solution:

$I_T = (-V_{EE})/R_E$ (Eq. 17-5)
$I_T = (-15\text{ V})/68\text{ k}\Omega$
$I_T = 220.6\ \mu$A

$I_E = 1/2\ I_T$ (Eq. 17-6)
$I_E = 1/2(220.6\ \mu\text{A})$
$I_E = 110.3\ \mu$A

$r'_e = 25\text{ mV}/I_E$ (Eq. 9-10)
$r'_e = 25\text{ mV}/110.3\ \mu\text{A}$
$r'_e = 226.7\ \Omega$

$A_v = R_C/r'_e$ (Eq. 17-10)
$A_v = 47\text{ k}\Omega/226.7\ \Omega$
$A_v = 207.3$

$v_{out} = A_v(v_1 - v_2)$ (Eq. 17-2)
$v_{out} = 207.3(0\text{ V} - 1\text{ mV})$
$v_{out} = -207$ mV

$z_{in} = 2\beta r'_e$ (Eq. 17-11)
$z_{in} = 2(275)(226.7\ \Omega)$
$z_{in} = 125$ kΩ

Answer: The output voltage is –207 mV, and the input impedance is 125 kΩ.

17-8. *Given:*

$A_v = 360$
$I_{in(biaS)} = 600$ nA
$I_{in(off)} = 100$ nA
$V_{in(off)} = 1$ mV
$R_{B1} = 10$ kΩ

Solution:

$V_{1err} = (R_{B1} - R_{B2})/I_{in(biaS)}$ (Eq. 17-16)
$V_{1err} = (10\text{ k}\Omega - 0)600\text{ nA}$
$V_{1err} = 6$ mV

$V_{2err} = (R_{B1} + R_{B2})(I_{in(off)}/2)$ (Eq. 17-17)
$V_{2err} = (10\text{ k}\Omega + 0)(100\text{ nA}/2)$
$V_{2err} = 0.5$ mV

$V_{3err} = V_{in(off)}$ (Eq. 17-18)
$V_{3err} = 1$ mV

$V_{error} = A_v(V_{1err} + V_{2err} + V_{3err})$ (Eq. 17-19)
$V_{error} = 360(6\text{ mV} + 0.5\text{ mV} + 1\text{ mV})$
$V_{error} = 2.7$ V

With base resistors equal.

$V_{1err} = 0.$ (Eq. 17-20)

$V_{2err} = R_B I_{in(off)}$ (Eq. 17-21)
$V_{2err} = (10\text{ k}\Omega)(100\text{ nA})$
$V_{2err} = 1$ mV

$V_{3err} = V_{in(off)}$ (Eq. 17-18)
$V_{3err} = 1$ mV

$V_{error} = A_v(V_{1err} + V_{2err} + V_{3err})$ (Eq. 17-19)
$V_{error} = 360(0\text{ mV} + 1\text{ mV} + 1\text{ mV})$
$V_{error} = 0.72$ V

Answer: The output error voltage is 2.7 V. If the base resistors are equal, the output error voltage is 0.72 V.

17-9. *Given:*

$A_v = 250$
$I_{in(biaS)} = 1\ \mu$A

$A_{v(CL)max} = (100\ k\Omega/2\ k\Omega) + 1$
$A_{v(CL)max} = 51$

$A_{v(CL)min} = (R_{2(min)}/R_1) + 1$ (Eq. 18-12)
$A_{v(CL)min} = (0\ k\Omega/2\ k\Omega) + 1$
$A_{v(CL)min} = 1$

$f_{2(CL)max} = f_{unity}/A_{v(CL)min}$ (Eq. 18-5)
$f_{2(CL)max} = 20\ MHz/1$
$f_{2(CL)max} = 20\ MHz$

$f_{2(CL)min} = f_{unity}/A_{v(CL)max}$ (Eq. 18-5)
$f_{2(CL)min} = 20\ MHz/51$
$f_{2(CL)min} = 392\ kHz$

Answer: The voltage gain has a range of 1 to 51 and a bandwidth of 392 kHz to 20 MHz.

18-16. *Answer:* The voltage across the closed-loop output impedance is the difference between the ideal 50 mV and the actual 49.98 mV. In other words, 0.02 mV is dropped across the closed-loop output impedance. The load current is 49.98 mV divided by 2 Ω, which is approximately 25 mA. Divide 0.02 mV by 25 mA to get 0.0008 Ω for the closed-loop output impedance.

18-17. *Given:*

$f = 15\ kHz$
$V_P = 2\ V$

Solution:

$S_S = 2\pi f V_P$
$S_S = 2\pi(15\ kHz)(2\ V)$
$S_S = 188\ mV/\mu s$

$S_S = 2\pi f V_P$
$S_S = 2\pi(30\ kHz)(2\ V)$
$S_S = 376\ mV/\mu s$

Answer: The initial slope is 188 mV/μs, with a peak of 2 V, and 376 mV/μs, with a frequency of 30 kHz.

18-18. *Answer:*

a. OP-07A
b. TL082 and TL084
c. LM12
d. OP-64E
e. OP-07A

18-19. *Answer:*

CMRR = 38 dB (from Fig. 18-6*a*)
MPP = 21 V (from Fig. 18-6*b*)
$A_v = 1000$ (from Fig. 18-6*c*)

18-20. *Given:*

$R_1 = 10\ k\Omega$
$R_2 = 20\ k\Omega$
$R_3 = 40\ k\Omega$
$R_{f(max)} = 100\ k\Omega$
$R_{f(min)} = 100\ k\Omega$
$v_1 = 50\ mVpp$
$v_1 = 90\ mVpp$
$v_1 = 160\ mVpp$

Solution: When the resistance is zero, the voltage gains are zero and the output voltage is zero.

$-A_{v1(CL)max} = -R_f/R_1$ (Eq. 18-3)
$-A_{v1(CL)max} = -100\ k\Omega/10\ k\Omega$
$-A_{v1(CL)max} = -10$

$-A_{v2(CL)max} = -R_f/R_1$ (Eq. 18-3)
$-A_{v2(CL)max} = -100\ k\Omega/20\ k\Omega$
$-A_{v2(CL)max} = -5$

$-A_{v3(CL)max} = -R_f/R_1$ (Eq. 18-3)
$-A_{v3(CL)max} = -100\ k\Omega/40\ k\Omega$
$-A_{v3(CL)max} = -2.5$

$v_{out} = A_{v1(CL)max}(v_{in1}) + A_{v2(CL)max}(v_{in2}) + A_{v3(CL)max}(v_{in3})$
$v_{out} = -10(50\ mVpp) + 5(90\ mVpp) + 2.5(160\ mVpp)$
$v_{out} = -1.35\ Vpp$

Answer: The maximum output voltage is 1.35 Vpp, and the minimum output voltage is zero.

18-21. *Given:*

$R_1 = 220\ \Omega$
$R_{F1} = 47\ k\Omega$
$R_{F2} = 18\ k\Omega$
$R_{F3} = 39\ k\Omega$

Solution:

$-A_{v1(CL)} = -R_{F1}/R_1$ (Eq. 18-3)
$-A_{v1(CL)} = -47\ k\Omega/220\ \Omega$
$-A_{v1(CL)} = -214$

$-A_{v2(CL)} = -R_{F2}/R_1$ (Eq. 18-3)
$-A_{v2(CL)} = -18\ k\Omega/220\ \Omega$
$-A_{v2(CL)} = -82$

$-A_{v3(CL)} = -R_{F3}/R_1$ (Eq. 18-3)
$-A_{v3(CL)} = -39\ k\Omega/220\ \Omega$
$-A_{v3(CL)} = -177$

Solution: The gain at position 1 is 214, at position 2 is 82, and at position 3 is 177.

18-22. *Given:*

$R_1 = 6\ k\Omega$ at position 2
$R_2 = 6\ k\Omega \| 3\ k\Omega$ at position 1 = 2 kΩ
$R_2 = 120\ k\Omega$
$f_{unity} = 1\ MHz$

Solution:

$A_{v1(CL)} = (R_2/R_1) + 1$ (Eq. 18-12)
$A_{v1(CL)} = (120\ k\Omega/2\ k\Omega)+ 1$
$A_{v1(CL)} = 61$

$A_{v2(CL)} = (R_2/R_1) + 1$ (Eq. 18-12)
$A_{v2(CL)} = (120\ k\Omega/6\ k\Omega) + 1$
$A_{v2(CL)} = 21$

$f_{2(CL)1} = f_{unity}/A_{v(CL1)}$ (Eq. 18-5)
$f_{2(CL)1} = 1\ MHz/61$
$f_{2(CL)1} = 16.4\ kHz$

$f_{2(CL)2} = f_{unity}/A_{v(CL1)(max)}$ (Eq. 18-5)
$f_{2(CL)2} = 1\ MHz/21$
$f_{2(CL)2} = 47.6\ kHz$

Answer: The voltage gain at position 1 is 61, with a bandwidth of 16.4 kHz, and at position 2 is 21, with a bandwidth of 47.6 kHz.

18-23. *Given:*

$R_1 = \infty$ at position 2
$R_1 = 3\ k\Omega$ at position 1
$R_2 = 120\ k\Omega$
$f_{unity} = 1\ MHz$
$A_{VOL} = 100{,}000$

Solution:

$A_{V1(CL)} = (R_2/R_1) + 1$ (Eq. 18-12)
$A_{V1(CL)} = (120\ k\Omega/3\ k\Omega) + 1$
$A_{V1(CL)} = 41$

At position 2, it becomes a voltage follower: $A_{vCL2} = 1$.

Answer: The voltage gain at position 1 is 41, and at position 2 is 1.

18-24. *Answer:* The output will go to positive or negative saturation.

18-25. *Answer:*

Position 1: The input voltage is applied directly to the noninverting input. Because of the virtual short between the noninverting and inverting input terminals, there is no ac voltage across the left 10-kΩ resistor. Since there is no ac voltage across the resistor, it can be removed from the circuit without changing the operation. With the resistor removed, the circuit reduces to a voltage follower and $A_{v(CL)} = 1$ and a closed-loop bandwidth of

$$f_{2(CL)} = \frac{f_{\text{unity}}}{A_{v(CL)}} = \frac{1\text{ MHz}}{1} = 1\text{ MHz}$$

Position 2: The circuit is an inverting amplifier. The magnitude of the voltage gain is $A_{v(CL)} = 1$. Note that the closed-loop bandwidth is only half as much because

$$f_{2(CL)} = \frac{f_{\text{unity}}}{A_{V(CL)}+1} = \frac{1\text{ MHz}}{1+1} = 500\text{ kHz}$$

This was covered briefly in the chapter. See the equation at the top of p. 633 and the brief explanation that follows. Chapter 19 discusses the closed-loop bandwidths in more detail.

18-26. *Answer:*

Position 1: With the left resistor open, the circuit reduces to a voltage follower and $A_{V(CL)} = 1$.
Position 2: With the left resistor open, the voltage gain is zero.

18-27. *Answer:* Go to positive or negative saturation.

18-28. *Given:*

$I_{\text{in(biaS)}} = 500$ nA
$I_{\text{in(off)}} = 200$ nA
$V_{\text{in(off)}} = 6$ mV
$R_1 = 2$ kΩ
$R_2 = 100$ kΩ
$C = 1$ μF

Solution:

$X_C = 1/2\pi fC$
$X_C = 1/[2\pi(0)(1\ \mu\text{F})]$
$X_C = \infty$

$R_1' = X_C + R_1$
$R_1' = \infty + 2$ kΩ
$R_1' = \infty$

$R_{B2} = R_1 \| R_2$ (Eq. 18-11)
$R_{B2} = \infty \| 100$ kΩ
$R_{B2} = 100$ kΩ

$V_{1\text{err}} = (R_{B1} - R_{B2})I_{\text{in(biaS)}}$ (Eq. 18-8)
$V_{1\text{err}} = (0 - 100\text{ k}\Omega)(500\text{ nA})$
$V_{1\text{err}} = 50$ mV

$V_{2\text{err}} = (R_{B1} + R_{B2})(I_{\text{in(off)}}/2)$ (Eq. 18-8)
$V_{2\text{err}} = (0 + 100\text{ k}\Omega)(200\text{ nA}/2)$
$V_{2\text{err}} = 10$ mV

$V_{3\text{err}} = V_{\text{in(off)}} = 6$ mV

$A_{V(CL)} = (R_2/R_1') + 1$ (Eq. 18-12)
$A_{V(CL)} = (100\text{ k}\Omega/\infty) + 1$
$A_{V(CL)} = 1$

$V_{\text{error}} = \pm A_{CL}(\pm V_{1\text{err}} \pm V_{2\text{err}} \pm V_{3\text{err}})$
$V_{\text{error}} = 1(50\text{ mV} + 10\text{ mV} + 6\text{ mV})$
$V_{\text{error}} = 66$ mV

Answer: The output voltage is 66 mV.

18-29. *Given:*

$R_1 = 2$ kΩ
$R_2 = 100$ kΩ
$C = 1$ μF
$v_{\text{in}} = 50$ mV pp
$f = 1$ kHz

Solution:

$X_C = 1/2\pi fC$
$X_C = 1/[2\pi(1\text{ kHz})(1\ \mu\text{F})]$
$X_C = 159\ \Omega$

Since X_C is less than one-tenth of 2 kΩ, the bottom of the 2 kΩ is approximately an ac ground.

$A_{V(CL)} = (R_2/R_1') + 1$ (Eq. 18-12)
$A_{V(CL)} = (100\text{ k}\Omega/2\text{ k}\Omega) + 1$
$A_{V(CL)} = 51$

$v_{\text{out}} = A_{V(CL)}v_{\text{in}}$
$v_{\text{out}} = 51(50\text{ mV pp})$
$v_{\text{out}} = 2.55$ V pp

Answer: The output voltage is 2.55 V.

18-30. *Given:*

$I_{\text{in(biaS)}} = 500$ nA
$I_{\text{in(off)}} = 200$ nA
$V_{\text{in(off)}} = 6$ mV
$R_1 = 2$ kΩ
$R_2 = 100$ kΩ

Solution:

$R_1' = X_C = R_1$
$R_1' = 0 + 2$ kΩ
$R_1' = 2$ kΩ

$R_{B2} = R_1 \| R_2$ (Eq. 18-11)
$R_{B2} = 2\text{ k}\Omega \| 100\text{ k}\Omega$
$R_{B2} = 1.96$ kΩ

$V_{1\text{err}} = (R_{B1} - R_{B2})I_{\text{in(biaS)}}$ (Eq. 18-8)
$V_{1\text{err}} = (0 - 1.96\text{ k}\Omega)(500\text{ nA})$
$V_{1\text{err}} = 980$ μV

$V_{2\text{err}} = (R_{B1} + R_{B2})(I_{\text{in(off)}}/2)$ (Eq. 18-8)
$V_{2\text{err}} = (0 + 1.96\text{ k}\Omega)(200\text{ nA}/2)$
$V_{2\text{err}} = 196$ μV

$V_{3\text{err}} = V_{\text{in(off)}} = 6$ mV

$A_{V(CL)} = (R_2/R_1') + 1$ (Eq. 18-12)
$A_{V(CL)} = (100\text{ k}\Omega/2\text{ k}\Omega) + 1$
$A_{V(CL)} = 51$

$V_{\text{error}} = \pm A_{V(CL)}(\pm V_{1\text{err}} \pm V_{2\text{err}} \pm V_{3\text{err}})$
$V_{\text{error}} = 51(980\ \mu\text{V} + 196\ \mu\text{V} + 6\text{ mV})$
$V_{\text{error}} = 366$ mV

Answer: The output voltage is 366 mV.

18-31. *Answer:*

For I_{B1}:
V_1—increase. Because of the increase in voltage drop across the resistor.
V_2—no change. Not affected.
V_{in}—increase. Because of the increase in V_1.
V_{out}—increase. Because of the increase in input voltage.
MPP—no change. Since the load resistance and V_{CC} did not change.
f_{max}—no change. Since slew rate did not change.

For I_{B2}:
V_1—no change. Not affected.
V_2—increase. Because of the increase in voltage drop across the resistor.

V_{in}—increase. Because of the increase in V_2.
V_{out}—increase. Because of the increase in input voltage.
MPP—no change. Since the load resistance and V_{CC} did not change.
f_{max}—no change. Since slew rate did not change.

18-32. *Given:*

For V_{CC}:
V_1—no change. Not affected.
V_2—no change. Not affected.
V_{in}—no change. Not affected.
V_{out}—no change. Not affected.
MPP—increase Since V_{CC} is increased.
f_{max}—no change. Since slew rate did not change.

18-33. *Given:*

V_1—no change. Not affected.
V_2—no change. Not affected.
V_{in}—no change. Not affected.
V_{out}—no change. Not affected.
MPP—no change. Since the load resistance and V_{CC} did not change.
f_{max}—increase. Since slew rate increased.

18-34. *Given:*

V_1—no change. Not affected.
V_2—no change. Not affected.
V_{in}—no change. Not affected.
V_{out}—no change. Not affected.
MPP—no change. Since the load resistance and V_{CC} did not change.
f_{max}—decrease. Since the increase in voltage causes the rate of voltage rise to increase.

Chapter 19 Negative Feedback

SELF-TEST

1. b	**8. b**	**15. b**	**22. d**
2. d	**9. b**	**16. d**	**23. d**
3. a	**10. b**	**17. c**	**24. b**
4. a	**11. d**	**18. b**	**25. a**
5. a	**12. b**	**19. c**	**26. b**
6. c	**13. b**	**20. b**	**27. d**
7. b	**14. b**	**21. c**	**28. a**

JOB INTERVIEW QUESTIONS

8. Increased voltage gain and possible oscillation.
12. Current amplifier and transconductance amplifier.

PROBLEMS

19-1. *Given:*

$R_1 = 2.7\ \text{k}\Omega$
$R_f = 68\ \text{k}\Omega$
$A_{VOL(dB)} = 88$ dB

Solution:

$B = R_1/(R_1 + R_f)$ (Eq. 19-6)
$B = 2.7\ \text{k}\Omega/(2.7\ \text{k}\Omega + 68\ \text{k}\Omega)$
$B = 0.038$

$A_V = 1/B$ (Eq. 19-4)
$A_V = 1/0.038$
$A_V = 26.32$

$A_v = \text{antilog}(A_{v(dB)}/20)$ (Eq. 16-15)
$A_v = \text{antilog}(88\ \text{dB}/20)$
$A_v = 25{,}119$

$\%\text{error} = 100\%(1 + A_{VOL}B)$ (Eq 19-5)
$\%\text{error} = 100\%[1 + 25{,}119(0.038)]$
$\%\text{error} = 0.10\%$

$A_V = A_{VOL}/(1 + A_{VOL}B)$ (Eq. 19-3)
$A_V = 25{,}119/[1 + 25{,}119(0.038)]$
$A_V = 26.29$

Answer: The feedback fraction is 0.038, the ideal closed-loop voltage gain is 26.32, the percent error is 0.10%, and the exact voltage gain is 26.29.

19-2. *Given:*

$R_1 = 2.7\ \text{k}\Omega$
$R_f = 39\ \text{k}\Omega$
$A_{VOL(\text{dB})} = 88$ dB

Solution:

$B = R_1/(R_1 + R_f)$ (Eq. 19-6)
$B = 2.7\ \text{k}\Omega/(2.7\ \text{k}\Omega + 39\ \text{k}\Omega)$
$B = 0.065$

$A_V = 1/B$ (Eq. 19-4)
$A_V = 1/0.065$
$A_V = 15.44$

Answer: The feedback fraction is 0.065, and the closed-loop voltage gain is 15.44.

19-3. *Given:*

$R_1 = 4.7\ \text{k}\Omega$
$R_f = 68\ \text{k}\Omega$
$A_{VOL(\text{dB})} = 88$ dB

Solution:

$B = R_1/(R_1 + R_f)$ (Eq. 19-6)
$B = 4.7\ \text{k}\Omega/(4.7\ \text{k}\Omega + 68\ \text{k}\Omega)$
$B = 0.065$

$A_V = 1/B$ (Eq. 19-4)
$A_V = 1/0.065$
$A_V = 15.47$

Answer: The feedback fraction is 0.065, and the closed-loop voltage gain is 15.47.

19-4. *Given:*

$R_1 = 2.7\ \text{k}\Omega$
$R_f = 68\ \text{k}\Omega$
$A_{VOL(\text{dB})} = 108$ dB

Solution:

$B = R_1/(R_1 + R_f)$ (Eq. 19-6)
$B = 2.7\ \text{k}\Omega/(2.7\ \text{k}\Omega + 68\ \text{k}\Omega)$
$B = 0.038$

$A_V = 1/B$ (Eq. 19-4)
$A_V = 1/0.038$
$A_V = 26.32$

$A_V = \text{antilog}(A_{VOL(\text{dB})}/20)$ (Eq. 16-15)
$A_V = \text{antilog}(108\ \text{dB}/20)$
$A_V = 251{,}189$

$\%\text{error} = 100\%(1 + A_{VOL}B)$ (Eq 19-5)
$\%\text{error} = 100\%[1 + 251{,}189(0.038)]$
$\%\text{error} = 0.01\%$

$A_V = A_{VOL}/(1 + A_{VOL}B)$ (Eq. 19-3)
$A_V = 251{,}189/[1 + 251{,}189(0.038)]$
$A_V = 26.31$

Solution

$v_{out(1)} = i_{in}R_3$ (from Table 19-2)
$v_{out(1)} = 1\ \mu A(10\ k\Omega)$
$v_{out(1)} = 10\ mV$

$A_{V(2)} = R_f/R_1 + 1$
$A_{V(2)} = 99\ k\Omega/1\ k\Omega + 1$
$A_{V(2)} = 100$

$v_{out(2)} = A_V(v_{in(2)})$
$v_{out(2)} = 100(10\ mV)$
$v_{out(2)} = 1\ V$

Answer: The output voltage is 1 V.

19-24. *Given:*

$R_f = 50\ k\Omega$
$R_{1(1)} = 1\ k\Omega$
$R_{1(2)} = 25\ k\Omega$
$R_{1(3)} = 100\ k\Omega$

Solution:

$A_{V1(CL)} = R_f/R_{1(1)} + 1$
$A_{V1(CL)} = 50\ k\Omega/1\ k\Omega + 1$
$A_{V1(CL)} = 51$

$A_{V2(CL)} = R_f/R_{1(2)} + 1$
$A_{V2(CL)} = 50\ k\Omega/25\ k\Omega + 1$
$A_{V2(CL)} = 3$

$A_{V3(CL)} = R_f/R_{1(3)} + 1$
$A_{V3(CL)} = 50\ k\Omega/100\ k\Omega + 1$
$A_{V3(CL)} = 1.5$

Answer: The voltage gains are 51 at the 1-kΩ position, 3 at the 25-kΩ position, and 1.5 at the 100-kΩ position.

19-25. *Given:*

$R_f = 50\ k\Omega$
$R_{1(1)} = 1\ k\Omega$
$R_{1(2)} = 25\ k\Omega$
$R_{1(3)} = 100\ k\Omega$
$A_{V1(CL)} = 51$ (from Prob. 19-24)
$A_{V2(CL)} = 3$ (from Prob. 19-24)
$A_{V3(CL)} = 1.5$ (from Prob. 19-24)
$v_{in} = 10\ mV$

Solution:

$v_{out(1)} = A_{V1(CL)}(v_{in})$
$v_{out(1)} = 51(10\ mV)$
$v_{out(1)} = 510\ mV$

$v_{out(2)} = A_{V2(CL)}(v_{in})$
$v_{out(2)} = 3(10\ mV)$
$v_{out(2)} = 30\ mV$

$v_{out(3)} = A_{V3(CL)}(v_{in})$
$v_{out(3)} = 1.5(10\ mV)$
$v_{out(3)} = 15\ mV$

Answer: The output voltages are 510 mV at the 1-kΩ position, 30 mV at the 25-kΩ position, and 15 mV at the 100-kΩ position.

19-26. *Given:*

$R_f = 50\ k\Omega$
$R_{1(1)} = 1\ k\Omega$
$R_{1(2)} = 25\ k\Omega$
$R_{1(3)} = 100\ k\Omega$
$A_{V1(CL)} = 51$ (from Prob. 19-24)
$A_{V2(CL)} = 3$ (from Prob. 19-24)
$A_{V3(CL)} = 1.5$ (from Prob. 19-24)
$A_{VOL} = 100{,}000$
$R_{in} = 2\ M\Omega$
$R_{out} = 75\ \Omega$

Solution:

$B_{(1)} = R_{1(1)}/(R_{1(1)} + R_f)$ (Eq. 19-6)
$B_{(1)} = 1\ k\Omega/(1\ k\Omega + 50\ k\Omega)$
$B_{(1)} = 0.0196$

$z_{in1(CL)} = (1 + A_{VOL}B_{(1)})R_{in}$ (Eq. 19-8)
$z_{in1(CL)} = (1 + (100{,}000)(0.0196))2\ M\Omega$
$z_{in1(CL)} = 3924\ M\Omega$

$z_{out1(CL)} = R_{out}/(1 + A_{VOL}B_{(1)})$ (Eq. 19-10)
$z_{out1(CL)} = 75\ \Omega/(1 + (100{,}000)(0.0196))$
$z_{out1(CL)} = 38\ m\Omega$

$B_{(2)} = R_{1(2)}/(R_{1(2)} + R_f)$ (Eq. 19-6)
$B_{(2)} = 25\ k\Omega/(25\ k\Omega + 50\ k\Omega)$
$B_{(2)} = 0.333$

$z_{in2(CL)} = (1 + A_{VOL}B_{(2)})R_{in}$ (Eq. 19-8)
$z_{in2(CL)} = (1 + (100{,}000)(0.333))2\ M\Omega$
$z_{in2(CL)} = 66{,}669\ M\Omega$

$z_{out2(CL)} = R_{out}/(1 + A_{VOL}B_{(2)})$ (Eq. 19-10)
$z_{out2(CL)} = 75\ \Omega/(1 + (100{,}000)(0.333))$
$z_{out2(CL)} = 2.5\ m\Omega$

$B_{(3)} = R_{1(3)}/(R_{1(3)} + R_f)$ (Eq. 19-6)
$B_{(3)} = 100\ k\Omega/(100\ k\Omega + 50\ k\Omega)$
$B_{(3)} = 0.667$

$z_{in3(CL)} = (1 + A_{VOL}B_{(3)})R_{in}$ (Eq. 19-8)
$z_{in3(CL)} = (1 + (100{,}000)(0.667))2\ M\Omega$
$z_{in3(CL)} = 133{,}335\ M\Omega$

$z_{out3(CL)} = R_{out}/(1 + A_{VOL}B_{(3)})$ (Eq. 19-10)
$z_{out3(CL)} = 75\ \Omega/(1 + (100{,}000)(0.667))$
$z_{out3(CL)} = 1.25\ m\Omega$

Answer: At the 1-kΩ position the input impedance is 3,924 MΩ and the output impedance is 38 mΩ. At the 25-kΩ position the input impedance is 66,669 MΩ and the output impedance is 2.5 mΩ. At the 100-kΩ position the input impedance is 133,335 MΩ and the output impedance is 1.25 mΩ. *Note:* The R_{CM} of the op amp is not included in the calculations for input impedance. See Example 19-2.

19-27. *Given:*

$I_{in(bias)} = 80\ nA$
$I_{in(off)} = 20\ nA$
$V_{in(off)} = 1\ mV$
$A_{VOL} = 100{,}000$
$R_f = 100\ k\Omega$
$R_{1(1)} = 1\ k\Omega$
$R_{1(2)} = 25\ k\Omega$
$R_{1(3)} = 100\ k\Omega$
$A_{V1(CL)} = 101$
$A_{V2(CL)} = 5$
$A_{V3(CL)} = 2$

Solution:

$R_{B2(1)} = R_{1(1)} \| R_f$ (Eq. 18-11)
$R_{B2(1)} = 1\ k\Omega \| 100\ k\Omega$
$R_{B2(1)} = 990\ \Omega$

$V_{1err(1)} = (R_{B1} - R_{B2(1)})I_{in(biaS)}$ (Eq. 18-8)
$V_{1err(1)} = (0 - 990\ \Omega)(80\ nA)$
$V_{1err(1)} = -79.2\ \mu V$

$V_{2err(1)} = (R_{B1} + R_{B2(1)})(I_{in(off)}/2)$ (Eq. 18-8)
$V_{2err(1)} = (0 + 990\ \Omega)(20\ nA/2)$
$V_{2err(1)} = 9.9\ \mu V$

$V_{3err(1)} = V_{in(off)} = 1\ mV$

$R_{min} = 130\ \Omega$
$R_{max} = 25.13\ k\Omega$
$f_{unity} = 1\ MHz$

Solution:

$B_{min} = (10\ k\Omega \| 130\ \Omega)/(10\ k\Omega \| 130\ \Omega + 180\ k\Omega)$
$B_{min} = 0.000712$

$B_{max} = (10\ k\Omega \| 25.13\ k\Omega)/(10\ k\Omega \| 25.13\ k\Omega + 180\ k\Omega)$
$B_{max} = 0.0382$

$f_{2(min)} = Bf_{unity}$
$f_{2(min)} = 0.000712(1\ MHz)$
$f_{2(min)} = 712\ Hz$

$f_{2(max)} = Bf_{unity}$
$f_{2(max)} = 0.0382(1\ MHz)$
$f_{2(max)} = 38.2\ kHz$

$$A_v = \frac{-R_f}{R_1} = \frac{-180\,k\Omega}{10\,k\Omega} = 18$$

Answer: The minimum bandwidth is 712 Hz and the maximum bandwidth is 38.2 kHz.

20-4. *Given:*

$R_1 = 1.5\ k\Omega$
$R_f = 100\ k\Omega$
$R_{min} = 100\ \Omega$
$R_{max} = 5.1\ k\Omega$
$f_{unity} = 1\ MHz$

Solution:

$B_{min} = (R_1 \| R_{min})/(R_1 \| R_{min} + R_f)$
$B_{min} = (1.5\ k\Omega \| 100\ \Omega)/(1.5\ k\Omega \| 100\ \Omega + 100\ k\Omega)$
$B_{min} = 0.000937$

$B_{max} = (R_1 \| R_{max})/(R_1 \| R_{max} + R_f)$
$B_{max} = (1.5\ k\Omega \| 5.1\ k\Omega)/(1.5\ k\Omega \| 5.1\ k\Omega + 100\ k\Omega)$
$B_{max} = 0.01146$

$f_{2(min)} = B_{min}f_{unity}$
$f_{2(min)} = 0.000937(1\ MHz)$
$f_{2(min)} = 937\ Hz$

$f_{2(max)} = B_{max}f_{unity}$
$f_{2(max)} = 0.01146(1\ MHz)$
$f_{2(max)} = 11.5\ kHz$

$A_V = -R_f/R_1$
$A_V = -100\ k\Omega/1.5\ k\Omega$
$A_V = -66.7$

$v_{out} = A_v v_{in}$
$v_{out} = -66.7(4\ mV)$
$v_{out} = 266.8\ mV$

Answer: The minimum bandwidth is 937 Hz and the maximum bandwidth is 11.5 kHz. The output voltage is 266.8 mV.

20-5. *Given:*

$R_1 = 2\ k\Omega$
$R_f = 82\ k\Omega$
$R_L = 25\ k\Omega$
$C_1 = 2.2\ \mu F$
$C_2 = 4.7\ \mu F$
$f_{unity} = 3\ MHz$

Solution:

$A_V = (R_f/R_1) + 1$
$A_V = (82\ k\Omega/2\ k\Omega) + 1$
$A_V = 42$

$f_2 = f_{unity}/A_V$
$f_2 = 3\ MHz/42$
$f_2 = 71.4\ kHz$

$f_{C1} = 1/(2\pi R_3 C_1)$
$f_{C1} = 1/[2\pi(100\ k\Omega)(2.2\ \mu F)]$
$f_{C1} = 0.72\ Hz$

$f_{C2} = 1/(2\pi R_L C_2)$
$f_{C2} = 1/[2\pi(25\ k\Omega)(4.7\ \mu F)]$
$f_{C2} = 1.35\ Hz$

$f_{C3} = 1/(2\pi R_1 C_3)$
$f_{C3} = 1/[2\pi(2\ k\Omega)(1\ \mu F)]$
$f_{C3} = 79.6\ Hz$

Answer: The midband voltage gain is 42, the upper cutoff frequency is 71.4 kHz, and the lower cutoff frequency is 79.6 Hz.

20-6. *Given:*

$R_1 = 3.3\ k\Omega$
$R_2 = 150\ k\Omega$
$R_3 = 100\ k\Omega$
$R_L = 10\ k\Omega$
$C_1 = 1\ \mu F$
$C_2 = 10\ \mu F$
$C_3 = 4.7\ \mu F$
$f_{unity} = 1\ MHz$

Solution:

$A_V = (R_2/R_1) + 1$
$A_V = (150\ k\Omega/3.3\ k\Omega) + 1$
$A_V = 46.5$

$f_2 = f_{unity}/A_V$
$f_2 = 1\ MHz/46.5$
$f_2 = 21.5\ kHz$

$f_{C1} = 1/(2\pi R_3 C_1)$
$f_{C1} = 1/[2\pi(100\ k\Omega)(1\ \mu F)]$
$f_{C1} = 1.59\ Hz$

$f_{C2} = 1/(2\pi R_L C_2)$
$f_{C2} = 1/[2\pi(10\ k\Omega)(10\ \mu F)]$
$f_{C2} = 1.59\ Hz$

$f_{C3} = 1/(2\pi R_1 C_3)$
$f_{C3} = 1/[2\pi(3.3\ k\Omega)(4.7\ \mu F)]$
$f_{C3} = 10.3\ Hz$

Answer: The midband voltage gain is 46.5, the upper cutoff frequency is 21.5 kHz, and the lower cutoff frequency is 10.3 Hz.

20-7. *Given:*

$R_1 = 2\ k\Omega$
$R_f = 100\ k\Omega$
$v_{in} = 10\ mV$

Solution:

$A_V = (R_f/R_1) + 1$
$A_V = (100\ k\Omega/2\ k\Omega) + 1$
$A_V = 51$

$v_{out} = A_v v_{in}$
$v_{out} = 51(10\ mV)$
$v_{out} = 510\ mV$

Answer: The output voltage at *A*, *B*, and *C* is 510 mV.

20-8. *Given:*

$R_1 = 91\ k\Omega$
$R_f = 12\ k\Omega$
$R_3 = 1\ k\Omega$
$v_{in} = 2\ mV$

Solution:

Low gate:
$A_V = (R_f/R_1) + 1$
$A_V = (12\text{ k}\Omega/91\text{ k}\Omega) + 1$
$A_V = 1.13$

$v_{out} = A_v v_{in}$
$v_{out} = 1.13(2\text{ mV})$
$v_{out} = 2.26\text{ mV}$

High gate:
$A_V = [R_f/(R_1\|R_3)] + 1$
$A_V = [12\text{ k}\Omega/(91\text{ k}\Omega\|1\text{ k}\Omega)] + 1$
$A_V = 13.1$

$v_{out} = A_v v_{in}$
$v_{out} = 13.1(2\text{ mV})$
$v_{out} = 26.2\text{ mV}$

Answer: When the gate is low, the output is 2.26 mV; when the gate is high, the output is 26.2 mV.

20-9. *Given:*

$R_1 = 20\text{ k}\Omega$
$R_f = 68\text{ k}\Omega$
$R_3 = 1\text{ k}\Omega$
$v_{in} = 1\text{ mV}$

Solution:

Low gate:
$A_V = (R_f/R_1) + 1$
$A_V = (68\text{ k}\Omega/20\text{ k}\Omega) + 1$
$A_V = 4.4$

$v_{out} = A_v v_{in}$
$v_{out} = 4.41(1\text{ mV})$
$v_{out} = 4.4\text{ mV}$

High gate:
$A_V = [R_f/(R_1\|R_3)] + 1$
$A_V = [68\text{ k}\Omega/(20\text{ k}\Omega\|1\text{ k}\Omega)] + 1$
$A_V = 72.4$

$v_{out} = A_v v_{in}$
$v_{out} = 72.4(1\text{ mV})$
$v_{out} = 72.4\text{ mV}$

Answer: When the gate is low, the output is 4.4 mV, and when the gate is high, the output is 72.4 mV.

20-10. *Given:*

$R_1 = 10\text{ k}\Omega$
$R_f = 10\text{ k}\Omega$
$V_{in} = 2.5\text{ V}$

Solution:

$A_V = (R_f/R_1) + 1$
$A_V = (10\text{ k}\Omega/10\text{ k}\Omega) + 1$
$A_V = 2$

$V_{out} = A_V(v_{in})$
$V_{out} = 2(2.5\text{ V})$
$V_{out} = 5\text{ V}$

Answer: The new output reference voltage is 5 V.

20-11. *Given:*

$R_1 = 1\text{ k}\Omega$
$R_f = 10\text{ k}\Omega$

Solution:

$-R_2/R_1 < A_v < 0$
$-10\text{ k}\Omega/1\text{ k}\Omega < A_v < 0$
$-10 < A_v < 0$

Answer: The maximum gain is –10, and the maximum positive gain is 0.

20-12. *Given:* $R_1 = R_2$

Solution: At ground the circuit is an inverting amplifier.

$A_V = -R_f/R_1$
$A_V = -1$

When the wiper is 10% away from ground, so that the noninverting gain will be 10% of its maximum of 2.

$A_{v(non)} = 10\%\ (2) = 0.2$
$A_V = A_{v(in)} + A_{v(non)}$
$A_V = -1 + 0.2$
$A_V = -0.8$

Answer: The gain with the wiper at ground is –1, and 10% away is –0.8.

20-13. *Given:*

$R = 5\text{ k}\Omega$
$nR = 75\text{ k}\Omega$
$nR/(n-1)R = 5.36\text{ k}\Omega$

Solution:

$A_V = -nR/R$
$A_V = -75\text{ k}\Omega/5\text{ k}\Omega$
$A_V = -15$

Answer: The maximum positive gain is 15, and the maximum negative gain is –15.

20-14. *Given:*

$R' = 10\text{ k}\Omega$
$R = 22\text{ k}\Omega$
$C = 0.02\ \mu\text{F}$
$f_{in} = 100\text{ Hz},\ 1\text{ kHz},\ 10\text{ kHz}$

Solution:

$f_C = 1/(2\pi RC)$
$f_C = 1/[(2\pi RC)(0.02\ \mu\text{F})]$
$f_C = 362\text{ Hz}$

$\phi = -2\arctan(f/f_C)$
$\phi = -2\arctan(100\text{ Hz}/362\text{ Hz})$
$\phi = -30.9°$

$\phi = -2\arctan(f/f_C)$
$\phi = -2\arctan(1\text{ kHz}/362\text{ Hz})$
$\phi = -140°$

$\phi = -2\arctan(f/f_C)$
$\phi = -2\arctan(10\text{ kHz}/362\text{ Hz})$
$\phi = -176°$

Answer: The phase shift is –30.9° at 100 Hz, –140° at 1 kHz, and –176° at 10 kHz.

20-15. *Given:*

$R_1 = 1.5\text{ k}\Omega$
$R_f = 30\text{ k}\Omega$

Solution:

$A_{v(inv)} = -R_f/R_1$ (Eq. 20-6)
$A_{v(inv)} = -30\text{ k}\Omega/1.5\text{ k}\Omega$
$A_{v(inv)} = -20$

$A_{v(non)} = [(R_2/R_1) + 1][R'_2/(R'_1 + R'_2)]$ (Eq. 20-7)
$A_{v(non)} = [(30\text{ k}\Omega/1.5\text{ k}\Omega) + 1][30\text{ k}\Omega/(1.5\text{ k}\Omega + 30\text{ k}\Omega)]$
$A_{v(non)} = 20$

$A_{v(CM)} = \pm 4(0.1\%) = \pm 4(0.001) = \pm 0.004$

Answer: The differential voltage gain is –20, and the common mode gain is ±0.004.

20-16. *Given:*

$R_1 = 1\text{ k}\Omega$
$R_f = 20\text{ k}\Omega$

Solution:

$A_{v(\text{inv})} = -R_f/R_1$ (Eq. 20-6)
$A_{v(\text{inv})} = -20\text{ k}\Omega/1\text{ k}\Omega$
$A_{iv(\text{inv})} = -20$

$A_{v(CM)} = \pm 4\ \Delta R/R$ (Eq. 20-5)
$A_{v(CM)} = \pm 4\ (1\%) = \pm 4(0.01)$
$A_{v(CM)} = \pm 0.04$

Answer: The differential voltage gain is –20, and the common-mode gain is ±0.04.

20-17. *Given:*

$R_1 = 10\text{ k}\Omega$
$R_2 = 20\text{ k}\Omega$
$R_3 = 20\text{ k}\Omega$
$R_4 = 10\text{ k}\Omega$

Solution:

$V_2 = [R_2/(R_1 + R_2)]V_{CC}$
$V_2 = [20\text{ k}\Omega/(10\text{ k}\Omega + 20\text{ k}\Omega)]15\text{ V}$
$V_2 = 10\text{ V}$

$V_4 = [R_4/(R_3 + R_4)]V_{CC}$
$V_4 = [10\text{ k}\Omega/(20\text{ k}\Omega + 10\text{ k}\Omega)]15\text{ V}$
$V_4 = 5$

Answer: No, the bridge is not balanced.

20-18. *Given:*

$R_1 = 1\text{ k}\Omega$
$\Delta R = 15\ \Omega$
$A_V = -100$

Solution:

$v_{\text{in}} = (\Delta R/4R)V_{CC}$
$v_{\text{in}} = (15\ \Omega/4\ (1\text{ k}\Omega))15\text{ V}$
$v_{\text{in}} = 56.3\text{ mV}$

$v_{\text{out}} = A_1(v_{\text{in}})$
$v_{\text{out}} = (-100)(56.3\text{ mV})$
$v_{\text{out}} = -5.63\text{ V}$

Answer: The output voltage is –5.63 V.

20-19. *Given:*

$R_1 = 1\text{ k}\Omega$
$R_f = 99\text{ k}\Omega$
$R = 10\text{ k}\Omega \pm 0.5\%$
$v_{\text{in}} = 2\text{ mV}$

Solution:

$A_V = (R_f/R_1) + 1$
$A_V = (99\text{ k}\Omega/1\text{ k}\Omega) + 1$
$A_V = 100$

$v_{\text{out}} = A_v v_{\text{in}}$
$v_{\text{out}} = 100(2\text{ mV})$
$v_{\text{out}} = 200\text{ mV}$

$A_{V(CM)} = \pm 2(\Delta R/R)$
$A_{V(CM)} = \pm 2(0.005)$
$A_{V(CM)} = \pm 0.01$

$\text{CMRR} = |A_V|/|A_{V(CM)}|$
$\text{CMRR} = 100/0.01$
$\text{CMRR} = 10{,}000$

Answer: The output voltage is 200 mV, and the CMRR is 10,000.

20-20. *Given:* $v_{\text{in}(CM)} = 5\text{ V}$

Solution: Since the first stage has a common-mode gain of 1, both sides have the same voltage of 5 V. The guard voltage is 5 V.

Answer: The guard voltage is 5 V.

20-21. *Given:*

$R_G = 1008\ \Omega$
$v_{\text{in}} = 20\text{ mV}$

Solution:

$A_V = (49.4\text{ k}\Omega/R_G) + 1$ (Eq. 20-17)
$A_V = (49.4\text{ k}\Omega/1008\ \Omega) + 1$
$A_V = 50$

$v_{\text{out}} = A_v(v_{\text{in}})$
$v_{\text{out}} = 50(20\text{ mV})$
$v_{\text{out}} = 1\text{ V}$

Answer: The output voltage is 1 V.

20-22. *Given:*

$R = 10\text{ k}\Omega$
$v_1 = -50\text{ mV}$
$v_2 = -30\text{ mV}$

Solution:

$v_{\text{out}} = v_1 - v_2$
$v_{\text{out}} = (-50\text{ mV}) - (-30\text{ mV})$
$v_{\text{out}} = -20\text{ mV}$

Answer: The output voltage is –20 mV.

20-23. *Given:*

$R_1 = 10\text{ k}\Omega$
$R_2 = 20\text{ k}\Omega$
$R_3 = 15\text{ k}\Omega$
$R_4 = 15\text{ k}\Omega$
$R_5 = 30\text{ k}\Omega$
$R_F = 75\text{ k}\Omega$
$v_1 = 1\text{ mV}$
$v_2 = 2\text{ mV}$
$v_3 = 3\text{ mV}$
$v_4 = 4\text{ mV}$

Solution:

$A_{v(1)} = -R_f/R_1$
$A_{v(1)} = -75\text{ k}\Omega/10\text{ k}\Omega$
$A_{v(1)} = -7.5$

$A_{v(2)} = -R_f/R_2$
$A_{v(2)} = -75\text{ k}\Omega/20\text{ k}\Omega$
$A_{v(2)} = -3.75$

$A_{v(3)} = \{[R_f/(R_1\|R_2)] + 1\}\{(R_4\|R_5)/[R_3 + (R_4\|R_5)]\}$
$A_{v(3)} = \{[75\text{ k}\Omega/(10\text{ k}\Omega\|20\text{ k}\Omega)] + 1\}\{(15\text{ k}\Omega\|30\text{ k}\Omega)/[15\text{ k}\Omega + (15\text{ k}\Omega\|30\text{ k}\Omega)]\}$
$A_{v(3)} = (12.25)(0.455)$
$A_{v(3)} = 5.57$

$A_{v(4)} = \{[R_f/(R_1\|R_2)] + 1\}\{(R_3\|R_5)/[R_4 + (R_3\|R_5)]\}$
$A_{v(4)} = \{[75\text{ k}\Omega/(10\text{ k}\Omega\|20\text{ k}\Omega)] + 1\}\{(15\text{ k}\Omega\|30\text{ k}\Omega)/[15\text{ k}\Omega + (15\text{ k}\Omega\|30\text{ k}\Omega)]\}$
$A_{v(4)} = (12.25)(0.4)$
$A_{v(4)} = 4.9$

$v_{\text{out}} = A_{v(1)}v_1 + A_{v(2)}v_2 + A_{v(3)}v_3 + A_{v(4)}v_4$
$v_{\text{out}} = -7.5(1\text{ mV}) + -3.75(2\text{ mV}) + 4.9(3\text{ mV}) + 4.9(4\text{ mV})$
$v_{\text{out}} = 19.3\text{ mV}$

Answer: The output voltage is 19.3 mV.

Solution:

$A_V = (R_f/R_1) + 1$
$A_V = (15\ \text{k}\Omega/1.5\ \text{k}\Omega) + 1$
$A_V = 11$

$f_1 = 1/[2\pi(R/2)C_1]$
$f_1 = 1/[2\pi(68\ \text{k}\Omega/2)(1\ \mu\text{F})]$
$f_1 = 4.68$ Hz

$f_2 = 1/(2\pi R_L C_2)$
$f_2 = 1/[2\pi(15\ \text{k}\Omega)(2.2\ \mu\text{F})]$
$f_2 = 4.82$ Hz

$f_3 = 1/(2\pi R_1 C_3)$
$f_3 = 1/[2\pi(1\ \text{k}\Omega)(3.3\ \mu\text{F})]$
$f_3 = 32.2$ Hz

Answer: The gain is 11, and the cutoff frequencies are $f_1 = 4.68$ Hz, $f_2 = 4.82$ Hz, and $f_3 = 32.2$ Hz.

CRITICAL THINKING

20-40. *Answer:* Since the terminal is floating, the output would be saturated or V_{CC}. To fix this problem, a large-value resistor could be connected to the noninverting terminal. This would keep it at ground potential during the transition and prevents a spike.

20-41. *Given:*

$R_{1(\text{min})} = 990\ \Omega$
$R_{1(\text{max})} = 1010\ \Omega$
$R_{f(\text{min})} = 99\ \text{k}\Omega$
$R_{f(\text{max})} = 101\ \text{k}\Omega$

Solution:

$A_{V(\text{min})} = -R_{f(\text{min})}/R_{1(\text{max})}$
$A_{V(\text{min})} = -99\ \text{k}\Omega/1010\ \Omega$
$A_{V(\text{min})} = 98$

$A_{V(\text{max})} = -R_{f(\text{max})}/R_{1(\text{min})}$
$A_{V(\text{max})} = -101\ \text{k}\Omega/990\ \Omega$
$A_{V(\text{max})} = 102$

Answer: The minimum gain is 98, and the maximum gain is 102.

20-42. *Given:*

Transistor:
$R_1 = 22\ \text{k}\Omega$
$R_f = 10\ \text{k}\Omega$
$R_S = 1\ \text{k}\Omega$
$R_E = 5.6\ \text{k}\Omega$
$R_C = 6.8\ \text{k}\Omega$
$V_{CC} = 15$V

Op amp
$R_1 = 1\ \text{k}\Omega$
$R_f = 47\ \text{k}\Omega$

Solution:

$V_{BB} = [R_f/(R_1 + R_f + R_S)]V_{CC}$ (Eq. 8-1)
$V_{BB} = [10\ \text{k}\Omega/(22\ \text{k}\Omega + 10\ \text{k}\Omega + 1\ \text{k}\Omega)]15$ V
$V_{BB} = 4.54$ V

$V_E = V_{BB} - V_{BE}$ (Eq. 8-2)
$V_E = 4.54\ \text{V} - 0.7$ V
$V_E = 3.84$ V

$I_E = V_E/R_E$ (Eq. 8-3)
$I_E = 3.84\ \text{V}/5.6\ \text{k}\Omega$
$I_E = 0.685$ mA

$r_e' = 25\ \text{mV}/I_E$ (Eq. 9-10)
$r_e' = 25\ \text{mV}/0.685$ mA
$r_e' = 36.5\ \Omega$

$r_c = R_C$
$r_c = 6.8\ \text{k}\Omega$

$A_v = r_c/r_e'$ (Eq. 10-7)
$A_v = 6.8\ \text{k}\Omega/36.5\ \Omega$
$A_v = 186$

Op amp:
$A_V = (R_f/R_1) + 1$
$A_V = (47\ \text{k}\Omega/1\ \text{k}\Omega) + 1$
$A_V = 48$

$A_V = (48)(186)$
$A_V = 9114$

Answer: The voltage gain is 9114.

20-43. *Given:*
$R_1 = 1\ \text{k}\Omega$
$R_f = 10\ \text{k}\Omega$
$R_L = 100\ \Omega$
$\beta = 50$
$v_{\text{in}} = 0.5\ V_{CC}$

Solution:

$A_V = -R_f/R_1$
$A_V = -10\ \text{k}\Omega/1\ \text{k}\Omega$
$A_V = -10$

$v_{\text{out}} = A_V(v_{\text{in}})$
$v_{\text{out}} = -10(0.5\ \text{V})$
$v_{\text{out}} = -5$ V

$I_{\text{out}} = v_{\text{out}}/R_L$
$I_{\text{out}} = -5\ \text{V}/100\ \Omega$
$I_{\text{out}} = 50$ mA

$I_B = I_{\text{out}}/\beta$
$I_B = 50\ \text{mA}/50$
$I_B = 1$ mA

Answer: The base current is 1 mA.

20-44. *Answer:*

Trouble 1: Since there is voltage at *E* and not at *F*, there is an open between *E* and *F*.

Trouble 2: Since the output is only 200 mV, which is the amplified output of *A*, R_2 is open.

Trouble 3: Since the input is 2 mV and the output is maximum, R_1 is shorted.

20-45. *Answer:*

Trouble 4: Since there is no voltage at *B*, there is an open between *K* and *B*.

Trouble 5: Since the voltage at *C* is 3 mV and the voltage at *D* is zero, there is an open between *C* and *D*.

Trouble 6: Since the voltage at *A* is zero, there is an open between *J* and *A*.

20-46. *Answer:*

Trouble 7: Since the input voltage is 3 mV and the output is maximum, R_3 is open.

Trouble 8: Since the output is only 250 mV, which is the amplified output of *B*, R_1 is open.

Trouble 9: Since the output voltage is the same as the input voltage, R_3 is shorted.

Trouble 10: Since the input is 5 mV and the output is maximum, R_2 is shorted.

21-20. *Given:*

$R_1 = 56$ kΩ
$R_f = 10$ kΩ
$C = 680$ pF

Solution:

$f_p = 1/(2\pi C\sqrt{R_1/R_f})$
$f_p = 1/[2\pi(680\text{ pF})\sqrt{(10\text{ k}\Omega)(56\text{ k}\Omega)}]$
$f_p = 9.89$ kHz

$Q = 0.5\sqrt{(R_1/R_f)}$
$Q = 0.5\sqrt{(56\text{k}\Omega)/(10\text{k}\Omega)}$
$Q = 1.18$

$K_c = 1.04$ (from Fig. 21-26)
$K_3 = 1.30$ (from Fig. 21-26)

$f_c = f_p/K_c$ (Eq. 21-31)
$f_c = 9.89$ kHz/1.04
$f_c = 9.51$ kHz

$f_3 = f_p/K_3$
$f_3 = 9.89$ kHz/1.30
$f_3 = 7.61$ kHz

Answer: The pole frequency is 9.89 kHz, the cutoff frequency is 9.51 kHz, the 3-dB frequency is 7.61 kHz, and the Q is 1.18.

21-21. *Given:*

$R_1 = 91$ kΩ
$R_f = 15$ kΩ
$C = 220$ pF

Solution:

$f_p = 1/(2\pi C\sqrt{R_1/R_f})$
$f_p = 1/[2\pi(220\text{ pF})\sqrt{(15\text{ k}\Omega)(91\text{ k}\Omega)}]$
$f_p = 19.6$ kHz

$Q = 0.5\sqrt{(R_1/R_f)}$
$Q = 0.5\sqrt{(91\text{k}\Omega)/(15\text{k}\Omega)}$
$Q = 1.23$

$K_c = 1.06$ (from Fig. 21-26)
$K_3 = 1.32$ (from Fig. 21-26)

$f_c = f_p/K_c$ (Eq. 21-31)
$f_c = 19.6$ kHz/1.06
$f_c = 18.5$ kHz

$f_3 = f_p/K_3$
$f_3 = 19.6$ kHz/1.32
$f_3 = 14.8$ kHz

Answer: The pole frequency is 19.6 kHz, the cutoff frequency is 18.5 kHz, the 3-dB frequency is 14.8 kHz, and the Q is 1.23.

21-22. *Given:*

$R_1 = 2$ kΩ
$R_f = 56$ kΩ
$C = 270$ pF

Solution:

$A_V = -R_f/2R_1$ (Eq. 21-35)
$A_V = -56$ kΩ/2(2 kΩ)
$A_V = -14$

$Q = 0.5\sqrt{(R_f/R_1)}$ (Eq. 21-36)
$Q = 0.5\sqrt{(56\text{ k}\Omega)/(2\text{ k}\Omega)}$
$Q = 2.65$

$f_0 = 1/(2\pi C\sqrt{(R_1/R_f)}$ (Eq. 21-38)
$f_0 = 1/[2\pi(270\text{ pF})\sqrt{(56\text{k}\Omega)(2\text{k}\Omega)}]$
$f_0 = 55.7$ kHz

Answer: The Q is 2.65, the voltage gain is –14, and the center frequency is 55.7 kHz.

21-23. *Given:*

$R_1 = 3.6$ kΩ
$R_f = 7.5$ kΩ
$R_3 = 27$ Ω
$C = 22$ nF

Solution:

$A_V = -R_f/2R_1$ (Eq. 21-35)
$A_V = -7.5$ kΩ/2(3.6 kΩ)
$A_V = -1.04$

$Q = 0.5\sqrt{[R_f/(R_1 \parallel R_3)]}$ (Eq. 21-40)
$Q = 0.5\sqrt{[7.5\text{k}\Omega/(2\text{k}\Omega \parallel 27\Omega)]}$
$Q = 8.39$

$f_0 = 1/(2\pi C\sqrt{(R_1 \parallel R_3)R_f}]$ (Eq. 21-41)
$f_0 = 1/[2\pi(22\text{ nF})\sqrt{(2\text{k}\Omega \parallel 27\Omega)(7.5\text{k}\Omega)}]$
$f_0 = 16.2$ kHz

Answer: The Q is 8.39, the voltage gain is –1.04, and the center frequency is 16.2 kHz.

21-24. *Given:*

$R_1 = 28$ kΩ
$R_3 = 1.8$ kΩ
$C = 1.8$ nF
$A_V = -1$

Solution:

$Q = 0.707\sqrt{[(R_1 + R_3)/R_3]}$ (Eq. 21-43)
$Q = 0.707\sqrt{[(28\text{k}\Omega + 1.8\text{k}\Omega)/1.8\text{k}\Omega]}$
$Q = 2.88$
$f_0 = 1/(2\pi C\sqrt{[2R_1(R_1 \parallel R_3)]})$ (Eq. 21-44)
$f_0 = 1/\{2\pi(1.8\text{ nF})\sqrt{[2(28\text{ k}\Omega)(28\text{ k}\Omega \parallel 1.8\text{k}\Omega)]}\}$
$f_0 = 9.09$ kHz

Answer: The Q is 2.88, the voltage gain is –1, and the center frequency is 9.09 kHz.

21-25. *Given:*

$R_1 = 20$ kΩ
$R_f = 10$ kΩ
$R = 56$ kΩ
$C = 180$ nF

Solution:

$A_V = (R_f/R_1) + 1$ (Eq. 21-46)
$A_V = (10$ kΩ/20 kΩ$) + 1$
$A_V = 1.5$

$f_0 = 1/(2\pi RC)$ (Eq. 21-47)
$f_0 = 1/[2\pi(56$ kΩ$)(180$ nF$)]$
$f_0 = 15.8$ Hz

$Q = 0.5/(2 - A_V)$ (Eq. 21-48)
$Q = 0.5/(2 - 1.5)$
$Q = 1$

$BW = f_0/Q$ (Eq. 21-34)
$BW = 15.8$ Hz/1
$BW = 15.8$ Hz

Answer: The voltage gain is 1.5, the Q is 1, the resonant frequency is 15.8 Hz, and the bandwidth is 15.8 Hz.

21-26. *Given:*

$R = 3.3$ kΩ
$C = 220$ nF

Roll-off = 20n dB/decade (Eq. 21-4a)
Roll-off = 20(10) dB/decade
Roll-off = 200 dB/decade

4 kHz is 1 octave above
Attenuation = 60 dB

8 kHz is 2 octaves above
Attenuation = 120 dB

20 kHz is 1 decade above
Attenuation = 200 dB

Answer: The attenuation is 60 dB at 4 kHz, 120 dB at 8 kHz, and 200 dB at 20 kHz.

21-34. *Given:*

$n = 2$
$R = 10\ \text{k}\Omega$
$f_c = 5\ \text{kHz}$

Solution:

$Q = 0.5\sqrt{C_2/C_1}$ (from Fig. 21-24)
$0.707 = 0.5\sqrt{C_2/C_1}$ (Butterworth response)
$1.414 = \sqrt{C_2/C_1}$
$2 = C_2/C_1$
$C_2 = 2C_1$
$fp = 1/2\pi R\sqrt{C_1(2C_1)}$
$fp = 1/2\pi\ RC_1\sqrt{2}$
$C_1 = 1/2\pi Rf_p\sqrt{2}$
$C_1 = 1/2\pi(10\ \text{k}\Omega)(5\ \text{kHz})\sqrt{2}$
$C_1 = 2.25\ \text{nF}$
$C_2 = 4.5\ \text{nF}$

21-35. *Given:*

$n = 2$
$R = 25\ \text{k}\Omega$
$f_c = 7.5\ \text{kHz}$
$A_p = 12\ \text{dB}$

Solution:

Since $A_p = 12$ dB, $K_c = 1.391$ and $Q = 4$ (from Table 21-3)

$f_c = K_c f_p$ (Eq. 21-23)
$f_p = f_c/K_c$
$f_p = 7.5\ \text{kHz}/1.391$
$f_p = 5.39\ \text{kHz}$
$Q = 0.5\sqrt{C_2/C_1}$ (from Fig. 21-25)
$4 = 0.5\sqrt{C_2/C_1}$ (Chebyshev response)

$8 = \sqrt{C_2/C_1}$
$64 = C_2/C_1$
$C_2 = 64C_1$
$fp = 1/2\pi R\sqrt{C_1(64C_1)}$
$fp = 1/16\pi RC_1$
$C_1 = 1/16\pi Rf_p$
$C_1 = 1/16\pi(25\ \text{k}\Omega)(5.39\ \text{kHz})$
$C_1 = 148\ \text{pF}$
$C_2 = 9.45\ \text{nF}$

Chapter 22 Nonlinear Op-Amp Circuits

SELF-TEST

1. d	**9. c**	**17. a**	**25. a**
2. a	**10. b**	**18. c**	**26. a**
3. c	**11. c**	**19. b**	**27. d**
4. b	**12. b**	**20. c**	**28. b**
5. c	**13. b**	**21. d**	**29. c**
6. a	**14. b**	**22. d**	**30. a**
7. a	**15. a**	**23. a**	
8. b	**16. b**	**24. b**	

JOB INTERVIEW QUESTIONS

5. It means using back-to-back zener diodes or other circuits to limit the output voltage swing.

8. An IC comparator does not have an internal compensating capacitor.

PROBLEMS

22-1. *Given:*

$A_{V(\text{dB})} = 106\ \text{dB}$
$V_{\text{Sat}} = \pm 20\ \text{V}$

Solution:

$A_{VOL} = \text{antilog}(A_{V(\text{dB})}/20)$ (Eq. 16-15)
$A_{VOL} = \text{antilog}(106\ \text{dB}/20)$
$A_{VOL} = 200{,}000$

$v_{\text{in(min)}} = \pm V_{\text{Sat}}/A_{VOL}$ (Eq. 22-1)
$v_{\text{in(min)}} = \pm 20\ \text{V}/200{,}000$
$v_{\text{in(min)}} = \pm 100\ \mu\text{V}$

Answer: An input voltage of 100 μV will produce positive saturation, assuming rail-to-rail output.

22-2. *Given:*

$v_{\text{in}} = 50\ \text{V}$
$R = 10\ \text{k}\Omega$

Answer:

$I_D = (v_{\text{in}} - 0.7\ \text{V})/R$
$I_D = (50\ \text{V} - 0.7\ \text{V})/10\ \text{k}\Omega$
$I_D = 4.93\ \text{mA}$

Solution: The diode current is 4.93 mA.

22-3. *Given:*

$V_Z = 6.8\ \text{V}$
$V_S = \pm 15\ \text{V}$

Solution:

$V_{\text{out}} = \pm(V_Z + V_D)$ (Eq. 22-1)
$V_{\text{out}} = \pm(6.8\ \text{V} + 0.7\ \text{V})$
$V_{\text{out}} = \pm 7.5\ \text{V}$

Answer: The output voltage will be limited to ±7.5 V.

22-4. *Given:* $V_S = \pm 12$ V

Answer: The output voltage would vary between 0.7 V and –12 V.

22-5. *Given:* $V_S = \pm 12$ V

Answer: When the strobe is high, the output is zero. When the strobe is low, the output will vary between 0.7 V and –9 V.

22-6. *Given:*

$V_S = \pm 15\ \text{V}$
$R_1 = 47\ \text{k}\Omega$
$R_2 = 12\ \text{k}\Omega$
$C = 0.5\ \mu\text{F}$

Solution:

$v_{\text{ref}} = [R_2/(R_1 + R_2)]V_{CC}$ (Eq. 22-2)
$v_{\text{ref}} = [12\ \text{k}\Omega/(47\ \text{k}\Omega + 12\ \text{k}\Omega)]15\ \text{V}$
$v_{\text{ref}} = 3.05\ \text{V}$

$f_C = 1/[2\pi(R_1 \| R_2)C]$ (Eq. 22-3)
$f_C = 1/[2\pi(47\ \text{k}\Omega \| 12\ \text{k}\Omega)\ 0.5\ \mu\text{F}]$
$f_C = 33.3\ \text{Hz}$

Answer: The reference voltage is 3.05 V, and the cutoff frequency is 33.3 Hz.

$f = 1/T$
$f = 122.4$ ms
$f = 45$ Hz

Answer: The lowest frequency is 45 Hz.

22-33. *Answer:* With the diode reversed, it becomes a negative peak detector and the output voltage is –106 mV.

22-34. *Given:* $v_{\text{in}} = 150$ mV peak

Answer: The output voltage is 150 mV.

22-35. *Given:* $v_{\text{in}} = 100$ mV peak

Solution:

$v_{\text{out}} = v_{\text{in}} + V$ peak (Eq. 22-21)
$v_{\text{out}} = 100$ mV peak + 100 mV peak
$v_{\text{out}} = 200$ mV peak

Answer: The output swings from 0 V to 200 mV peak.

22-36. *Given:*

$R_L = 10\ \text{k}\Omega$
$C = 4.7\ \mu\text{F}$

Solution:

$R_LC > 10T$ (Eq. 22-20)
$R_LC = 10T$ for the highest period or lowest frequency
$[(10\ \text{k}\Omega)(4.7\ \mu\text{F})]/10 = T$
$T = 4.7$ ms

$f = 1/T$
$f = 1/4.7$ ms
$f = 213$ Hz

Answer: The lowest frequency is 213 Hz.

22-37. *Given:* $f = 10$ kHz

Solution:

1 Hz = 1 cycle/second

10 kHz = 10,000 cycles/second or 10,000 cycles in 1 second

Each cycle has two transitions (low to high and high to low); thus there are 2 pulses per cycle.
10,000 cycles in 1 second × 2 pulses/cycle = 20,000 pulses in 1 second.

Answer: There are 20,000 pulses in 1 second.

22-38. *Given:* $f = 1$ kHz

Solution:

Since there are 2 pulses per cycle, a pulse occurs every $T/2$.

$T = 1/f$
$T = 1/1$ kHz
$T = 1$ mS

Answer: A pulse occurs every $T/2$ or 0.5 mS.

CRITICAL THINKING

22-39. *Answer:* Make the 3.3-kΩ resistor a variable so that it can be adjusted to any desired value.

22-40. *Given:*

$R = 1\ \text{k}\Omega$
$C = 50$ pF

Solution: Risetime is from the 10% point to the 90% point (discussed in Chap. 16). Using the universal time constant chart, it takes about 3 time constants to go from 10% to 90%.

$T_R \approx 2.2(RC)$ (Eq. 16-28)
$T_R \approx 2.2(1\ \text{k}\Omega)(50\ \text{pF})$
$T_R \approx 110$ ns

Answer: The risetime is 110 ns.

22-41. *Given:*

$R_1 = 33\ \text{k}\Omega$
$R_f = 3.3\ \text{k}\Omega$
$C = 47\ \mu\text{F}$
$V_{\text{ripple}} = 1$ V rms

Solution:

$f_C = 1/[2\pi(R_1 \| R_f)C]$ (from Fig. 22-11)
$f_C = 1/[2\pi(33\ \text{k}\Omega \| 3.3\ \text{k}\Omega)47\ \mu\text{F}]$
$f_C = 1.1$ Hz

The power supply ripple is 120 Hz because rectification. This is 2 decades above the cutoff frequency. Since there is one capacitor, the roll-off is 20 dB/decade. The input is attenuated by 40 dB, equivalent to 0.01.

$$v_{tb} = \frac{3.3\ \text{k}\Omega}{33\ \text{k}\Omega + 3.3\ \text{k}\Omega}(1\text{V}) = 0.1\text{V}$$

$$v_{\text{out}} = (0.01)(0.1\ \text{V}) = 0.001\ \text{V}$$

Answer: The cutoff frequency is 1:1 Hz, and the ripple voltage at the inverting input is 0.001 V rms.

22-42. *Given:*

$V_{CC} = 15$ V
$R_1 = 33\ \text{k}\Omega$
$R_f = 3.3\ \text{k}\Omega$

$v_{\text{in(peak)}} = 5$ V
$v_{\text{ref}} = 1.36$ V (from Prob. 22-9)

$\theta = 16°$ and $164°$ (from Prob. 22-9)
D = 41% (from Prob. 22-9)

Solution:

$I_{\text{high}} = V/R$
$I_{\text{high}} = 5\ \text{V}/1\ \text{k}\Omega$
$I_{\text{high}} = 5$ mA

Since the output is high only 41% of the time, the average current is:

$I_{\text{ave}} = Di_{\text{high}}$
$I_{\text{ave}} = (0.41)(5\ \text{mA})$
$I_{\text{ave}} = 2.05$ mA

Answer: The average current is 2.05 mA.

22-43. *Given:*

$R_1 = 1.5\ \text{k}\Omega \pm 5\%$
$R_f = 68\ \text{k}\Omega \pm 5\%$
$V_{\text{Sat}} = 13.5$ V

Solution:

$R_{1(\max)} = 1.5\ \text{k}\Omega + 5\%(1.5\ \text{k}\Omega) = 1575\ \Omega$
$R_{1(\min)} = 1.5\ \text{k}\Omega - 5\%(1.5\ \text{k}\Omega) = 1425\ \Omega$
$R_{f(\max)} = 68\ \text{k}\Omega + 5\%(68\ \text{k}\Omega) = 71.4\ \text{k}\Omega$
$R_{f(\min)} = 68\ \text{k}\Omega - 5\%(68\ \text{k}\Omega) = 64.6\ \text{k}\Omega$

$B_{(\min)} = \text{R}_{1(\min)}/(\text{R}_{1(\min)} + \text{R}_{f(\max)})$ (Eq. 22-4)
$B_{(\min)} = 1425\ \Omega/(1425\ \text{k}\Omega + 71.4\ \text{k}\Omega)$
$B_{(\min)} = 0.0196$

$H_{(\min)} = 2B_{(\min)}\ V_{Sat}$ (Eq. 22-9)
$H_{(\min)} = 2(0.0196)(13.5\ \text{V})$
$H_{(\min)} = 0.529$ V

Answer: The minimum hysteresis is 0.529 V.

8. There must be an unwanted positive feedback path between the output and the input of the three-stage amplifier. Low-frequency oscillations may be caused by the high power-supply impedance. You can try using a large filter capacitor at the supply point for each stage. If this docs not work, then a power supply with better regulation is needed. For high-frequency oscillations, you can try shielding the stages, using a single ground point, filter capacitors on each stage supply, and ferrite beads on each base or gate lead.

PROBLEMS

23-1. *Given:* $R_F = 1\ \text{k}\Omega$

Solution: The oscillator becomes stable with a lamp resistance of 500 Ω and from the graph a lamp voltage of 3 V rms.

$I_L = 3\ \text{V}/500\ \Omega$
$I_L = 6\ \text{mA}$

$V_{\text{out}} = I_L(R_F + R_L)$
$V_{\text{out}} = 6\ \text{mA}(1\ \text{k}\Omega + 500\ \Omega)$
$V_{\text{out}} = 9\ \text{V rms}$

Answer: The output voltage is 9 V rms.

23-2. *Given:*

$C = 200\ \text{pF}$
$R_{\text{min}} = 2\ \text{k}\Omega$
$R_{\text{max}} = 24\ \text{k}\Omega$

Solution:

$f_{r(\text{max})} = 1/[2\pi R_{\text{min}}C]$ (Eq. 23-4)
$f_{r(\text{max})} = 1/[2\pi(2.2\ \text{k}\Omega)(200\ \text{pF})]$
$f_{r(\text{max})} = 398\ \text{kHz}$

$f_{r(\text{min})} = 1/[2\pi R_{\text{max}}C]$ (Eq. 23-4)
$f_{r(\text{min})} = 1/[2\pi(2.4\ \text{k}\Omega)(200\ \text{pF})]$
$f_{r(\text{min})} = 33.2\ \text{kHz}$

Answer: The maximum frequency is 398 kHz, and the minimum frequency is 33.2 kHz.

23-3a. *Given:*

$C = 0.2\ \mu\text{F}$
$R_{\text{min}} = 2\ \text{k}\Omega$
$R_{\text{max}} = 24\ \text{k}\Omega$

Solution:

$f_{r(\text{max})} = 1/[2\pi R_{\text{min}}C]$ (Eq. 23-4)
$f_{r(\text{max})} = 1/[2\pi(2\ \text{k}\Omega)(0.2\ \mu\text{F})]$
$f_{r(\text{max})} = 398\ \text{Hz}$

$f_{r(\text{min})} = 1/[2\pi R_{\text{max}}C]$ (Eq. 23-4)
$f_{r(\text{min})} = 1/[2\pi(24\ \text{k}\Omega)(0.2\ \mu\text{F})]$
$f_{r(\text{min})} = 33.2\ \text{Hz}$

Answer: The maximum frequency is 398 Hz, and the minimum frequency is 33.2 Hz.

23-3b. *Given:*

$C = 0.02\ \mu\text{F}$
$R_{\text{min}} = 2\ \text{k}\Omega$
$R_{\text{max}} = 24\ \text{k}\Omega$

Solution:

$f_{r(\text{max})} = 1/[2\pi R_{\text{min}}C]$ (Eq. 23-4)
$f_{r(\text{max})} = 1/[2\pi(2\ \text{k}\Omega)(0.02\ \mu\text{F})]$
$f_{r(\text{max})} = 3.98\ \text{kHz}$

$f_{r(\text{min})} = 1/[2\pi R_{\text{max}}C]$ (Eq. 23-4)
$f_{r(\text{min})} = 1/[2\pi(24\ \text{k}\Omega)(0.02\ \mu\text{F})]$
$f_{r(\text{min})} = 332\ \text{Hz}$

Answer: The maximum frequency is 3.98 kHz, and the minimum frequency is 332 Hz.

23-3c. *Given:*

$C = 0.002\ \mu\text{F}$
$R_{\text{min}} = 2\ \text{k}\Omega$
$R_{\text{max}} = 24\ \text{k}\Omega$

Solution:

$f_{r(\text{max})}= 1/[2\pi R_{\text{min}}C]$ (Eq. 23-4)
$f_{r(\text{max})} = 1/[2\pi(2\ \text{k}\Omega)(0.002\ \mu\text{F})]$
$f_{r(\text{max})} = 39.8\ \text{kHz}$

$f_{r(\text{min})} = 1/[2\pi R_{\text{max}}C]$ (Eq. 23-4)
$f_{r(\text{min})} = 1/[2\pi(24\ \text{k}\Omega)(0.002\ \mu\text{F})]$
$f_{r(\text{min})} = 3.32\ \text{kHz}$

Answer: The maximum frequency is 39.8 kHz, and the minimum frequency is 3.32 kHz.

23-3d. *Given:*

$C = 200\ \text{pF}$
$R_{\text{min}} = 2\ \text{k}\Omega$
$R_{\text{max}} = 24\ \text{k}\Omega$

Solution:

$f_{r(\text{max})} = 1/[2\pi R_{\text{min}}C]$ (Eq. 23-4)
$f_{r(\text{max})} = 1/[2\pi(2\ \text{k}\Omega)(200\ \text{pF})]$
$f_{r(\text{max})} = 398\ \text{kHz}$

$f_{r(\text{min})} = 1/[2\pi R_{\text{max}}C]$ (Eq. 23-4)
$f_{r(\text{min})} = 1/[2\pi(24\ \text{k}\Omega)(200\ \text{pF})]$
$f_{r(\text{min})} = 33.2\ \text{kHz}$

Answer: The maximum frequency is 398 kHz, and the minimum frequency is 33.2 kHz.

23-4. *Given:*

$V_{\text{out}} = 6\ \text{V rms}$
$R_F = 2R_{\text{lamp}}$

Solution: Since the lamp resistance is one-third of the total resistance, its voltage will be one-third of the total voltage, or 2 V rms. According to the graph, the lamp resistance would be 350 Ω, so the feedback resistor would need to be twice that, or 700 Ω.

Answer: Change the feedback resistor to 700 Ω.

23-5. *Given:* Maximum frequency is 398 kHz, from Prob. 23-3.

Solution: 1 decade above 398 kHz is 3.98 MHz.

Answer: The cutoff frequency is 3.98 MHz.

23-6. *Given:*

$R = 10\ \text{k}\Omega$
$C = 0.01\ \mu\text{F}$

Solution:

$f_r = 1/[2\pi RC]$ (Eq. 23-4)
$f_r = 1/[2\pi(10\ \text{k}\Omega)(0.01\ \mu\text{F})]$
$f_r = 1.59\ \text{kHz}$

Answer: The resonant frequency is 1.59 kHz.

23-7. *Given:*

$R = 20\ \text{k}\Omega$
$C = 0.02\ \mu\text{F}$

Solution:

$f_r = 1/[2\pi RC]$ (Eq. 23-4)
$f_r = 1/[2\pi(20\ \text{k}\Omega)(0.02\ \mu\text{F})]$
$f_r = 398\ \text{Hz}$

Answer: The resonant frequency is 398 Hz.

23-8. *Given:*

$R_1 = 10\text{ k}\Omega$
$R_2 = 5\text{ k}\Omega$
$R_E = 1\text{ k}\Omega$
$V_{BE} = 0.7\text{ V}$
$V_{CC} = 12\text{ V}$

Solution:

$V_B = [R_2/(R_1 + R_2)]V_{CC}$ (Eq. 8-1)
$V_B = [5\text{ k}\Omega/(10\text{ k}\Omega + 5\text{ k}\Omega)]12\text{ V}$
$V_B = 4\text{ V}$

$V_E = V_B - V_{BE}$ (Eq. 8-2)
$V_E = 4\text{ V} - 0.7\text{ V}$
$V_E = 3.3\text{ V}$

$I_E = V_E/R_E$ (Eq. 8-3)
$I_E = 3.3\text{ V}/1\text{ k}\Omega$
$I_E = 3.3\text{ mA}$

Since the RF choke is a short to direct current, the collector voltage is 12 V.

$V_{CE} = V_C - V_E$ (Eq. 8-6)
$V_{CE} = 12\text{ V} - 3.3\text{ V}$
$V_{CE} = 8.7\text{ V}$

Answer: The emitter current is 3.3 mA, and the collector-to-emitter voltage is 8.7 V.

23-9. *Given:*

$C_1 = 0.001\ \mu\text{F}$
$C_2 = 0.01\ \mu\text{F}$
$L = 10\ \mu\text{H}$

Solution:

$C = C_1C_2/(C_1 + C_2)$ (Eq. 23-6)
$C = (0.001\ \mu\text{F})(0.01\ \mu\text{F})/(0.001\ \mu\text{F} + 0.01\ \mu\text{F})$
$C = 909\text{ pF}$

$f_r = 1/\left(2\pi\sqrt{LC}\right)$ (Eq. 23-5)
$f_r = 1/\left(2\pi\sqrt{(10\ \mu\text{H})(909\text{ pF})}\right)$
$f_r = 1.67\text{ MHz}$

$B = C_1/C_2$ (Eq. 23-7)
$B = 0.001\ \mu\text{F}/0.01\ \mu\text{F}$
$B = 0.10$

$A_{\text{v(min)}} = C_2/C_1$ (Eq. 23-8)
$A_{\text{v(min)}} = 0.001\ \mu\text{F}/0.01\ \mu\text{F}$
$A_{\text{v(min)}} = 10$

Answer: The frequency is 1.67 MHz, the feedback fraction is 0.10, and the minimum gain is 10.

23-10. *Given:*

$C_1 = 0.001\ \mu\text{F}$
$C_2 = 0.01\ \mu\text{F}$

Solution:

$B = C_1/(C_1 + C_2)$
$B = 0.001\ \mu\text{F}/(0.001\ \mu\text{F} + 0.01\ \mu\text{F})$
$B = 0.091$

Answer: The feedback fraction is 0.091.

23-11. *Given:*

$C_1 = 0.001\ \mu\text{F}$
$C_2 = 0.01\ \mu\text{F}$
$L = 20\ \mu\text{H}$

Solution:

$C = C_1C_2/(C_1 + C_2)$ (Eq. 23-6)
$C = (0.001\ \mu\text{F})(0.01\ \mu\text{F})/(0.001\ \mu\text{F} + 0.01\ \mu\text{F})$
$C = 909\text{ pF}$

$f_r = 1/(2\pi\sqrt{LC})$ (Eq. 23-5)
$f_r = 1/(2\pi\sqrt{(20\ \mu\text{H})(909\text{ pF})})$
$f_r = 1.18\text{ MHz}$

Answer: The frequency is 1.18 MHz.

23-12. *Answer:* Reduce the inductance by a factor of 4 (since there is a square root in the denominator).

23-13. *Given:*

$C_1 = 0.001\ \mu\text{F}$
$C_2 = 0.01\ \mu\text{F}$
$C_3 = 47\text{ pF}$
$L = 10\ \mu\text{H}$

Solution:

$f_r = 1/(2\pi\sqrt{LC_3})$ (Eq. 23-18)
$f_r = 1/(2\pi\sqrt{(10\ \mu\text{H})(47\text{ pF})})$
$f_r = 7.34\text{ MHz}$

Answer: The frequency is 7.34 MHz.

23-14. *Given:*

$L_1 = 1\ \mu\text{H}$
$L_2 = 0.2\ \mu\text{H}$
$C = 1000\text{ pF}$

Solution:

$B = L_2L_1$ (Eq. 23-16)
$B = 0.2\ \mu\text{H}/1\ \mu\text{H}$
$B = 0.2$

$L = L_1 + L_2$
$L = 1\ \mu\text{H} + 0.2\ \mu\text{H}$
$L = 1.2\ \mu\text{H}$

$f_r = 1/[2\pi\sqrt{LC}]$ (Eq. 23-5)
$f_r = 1/[2\pi\sqrt{(1.2\ \mu\text{H})(1000\text{ pF})}]$
$f_r = 4.59\text{ MHz}$

$A_{\text{v(min)}} = L_1/L_2$
$A_{\text{v(min)}} = 1\ \mu\text{H}/0.2\ \mu\text{H}$
$A_{\text{v(min)}} = 5$

Answer: The frequency is 4.59 MHz, the feedback fraction is 0.2, and the minimum gain is 5.

23-15. *Given:*

$M = 0.1\ \mu\text{H}$
$L = 3.3\ \mu\text{H}$

Solution:

$B = M/L$ (Eq. 23-14)
$B = 0.1\ \mu\text{H}/3.3\ \mu\text{H}$
$B = 0.030$

$A_{\text{v(min)}} = L/M$
$A_{\text{v(min)}} = 3.3\ \mu\text{H}/0.1\ \mu\text{H}$
$A_{\text{v(min)}} = 33$

Answer: The feedback fraction is 0.03, and the minimum gain is 33.

23-16. *Given:* $f = 5\text{ MHz}$

Answer: The first overtone is 10 MHz, the second overtone is 15 MHz, and the third overtone is 20 MHz.

23-17. *Answer:* Since the frequency is inversely proportional to thickness, if thickness is reduced by 1% the frequency will increase by 1%.

Answer: The period is 100 μs, the quiescent pulse width is 5.61 μs, the maximum pulse width is 8.66 μs, the minimum pulse width is 3.71 μs, the maximum duty cycle is 0.0866, and the minimum duty cycle is 0.0371.

23-24. *Given:*

$V_{CC} = 10$ V
$R_1 = 1.2$ kΩ
$R_2 = 1.5$ kΩ
$C = 4.7$ nF
$v_{mod} = 1.5$ V

Solution:

$W = 0.693(R_1 + R_2)C$ (Eq. 23-26)
$W = 0.693(1.2$ kΩ $+ 1.5$ kΩ$)(4.7$ nF$)$
$W = 8.79$ μs

$T = 0.693(R_1 + 2R_2)C$ (Eq. 23-27)
$T = 0.693[1.2$ kΩ $+ 2(1.5$ kΩ$)](4.7$ nF$)$
$T = 13.68$ μs

$UTP_{max} = 2V_{CC}/3 + v_{mod}$ (Eq. 23-34)
$UTP_{max} = 2(10$ V$)/3 + 1.5$ V
$UTP_{max} = 8.17$ V

$UTP_{min} = 2V_{CC}/3 - v_{mod}$ (Eq. 23-34)
$UTP_{min} = 2(10$ V$)/3 - 1.5$ V
$UTP_{min} = 5.17$ V

$W_{max} = -(R_1 + R_2)C1n[(V_{CC} - UTP_{max})/(V_{CC} - 0.5UTP_{max})]$ (Eq. 23-35)
$W_{max} = -\{[(1.2$ kΩ $+ 1.5$ kΩ$)(4.7$ nF$)]\ln[(10 - 8.17$ V$)/(10$ V $- 0.5(8.17$ V$)]\}$
$W_{max} = 14.89$ μs

$W_{min} = -(R_1 + R_2)C1n[(V_{CC} - UTP_{min})/(V_{CC} - 0.5UTP_{min})]$ (Eq. 23-35)
$W_{min} = -\{[(1.2$ kΩ $+ 1.5$ kΩ$)(4.7$ nF$)]\ln[(10 - 5.17$ V$)/(10$ V $- 0.5(5.17$ V$)]\}$
$W_{min} = 5.44$ μs

Space $= 0.693R_2C$
Space $= 0.693(1.5$ kΩ$)(4.7$ nF$)$
Space $= 4.89$ μs

Answer: The quiescent pulse width is 8.79 μs, the quiescent period is 13.69 μs, the maximum pulse width is 14.89 μs, the minimum pulse width is 5.44 μs, and the space between pulses is 4.89 μs.

23-25. *Given:*

$I_C = 0.5$ mA
$V_{CC} = 10$ V
$C = 47$ nF

Solution:

$S = I_C/C$ (Eq. 23-39)
$S = 0.5$ mA/47 nF
$S = 10.6$ V/mS

$V = 2V_{CC}/3$ (Eq. 23-40)
$V = 2(10$ V$)/3$
$V = 6.67$ V

$T = 2V_{CC}/3S$ (Eq. 23-41)
$T = 2(10$ V$)/3(10.6$ V/mS$)$
$T = 0.629$ mS

Answer: The slope is 10.6 V/mS, the peak value is 6.67 V, and the duration is 0.629 mS.

23-26. *Given:*

S_1 = Closed
$R = 20$ kΩ
$R_3 = 40$ kΩ
$C = 0.1$ μF

Solution:

The waveform is a sine wave.
$f = 1.1RC$
$f = 1/(20$ kΩ$)(0.1$ μF$)$
$f = 500$ Hz

Amplitude = 2.4 V_p
Amplitude = 4.8 V_{pp}

Answer: The output is a sine wave at a frequency of 500 Hz and a peak voltage of 2.4 V.

23-27. *Given:*

S_1 = Open
$R = 10$ kΩ
$R_3 = 40$ kΩ
$C = 0.01$ μF

Solution:

The waveform is a triangle wave.
$f = 1.1RC$
$f = 1/(10$ kΩ$)(0.01$ μF$)$
$f = 10$ kHz

Amplitude = 5 V_p
Amplitude = 10 V_{pp}

Answer: The output is a triangle wave at a frequency of 10 kHz and a peak voltage of 5 V.

23-28. *Given:*

$R_1 = 2$ kΩ
$R_2 = 10$ kΩ
$C = 0.01$ μF

Solution:

$$f = \frac{2}{C}\left(\frac{1}{R_1 + R_2}\right)$$

$$f = \frac{2}{0.1\ \mu\text{F}}\left(\frac{1}{2\ \text{k}\Omega + 10\ \text{k}\Omega}\right)$$

$f = 1.67$ kHz

$D = R_1/(R_1 + R_2)$
$D = 2$ kΩ$/(2$ kΩ $+ 10$ kΩ$)$
$D = 0.167$

Answer: The frequency is 1.67 kHz, and the duty cycle is 0.167.

23-29a. Decrease. With the lamp open, there is no path for feedback current. Thus the voltage at the inverting terminal will equal the output voltage and it should be driven to 0 V.

23-29b. Increase. With the inverting input grounded, there is no feedback and the gain is open-loop gain and the output will be saturation.

23-29c. Same. The upper potentiometer affects frequency, not output voltage.

23-29d. Same. Unless the supply falls low enough for clipping.

23-29e. Same. Only a very small change at the output.

23-30. *Answer:*

1. Shorted inductor
2. Open inductor
3. Shorted capacitors
4. Open capacitors
5. Open in the feedback path
6. Loss of the power supply

TABLE 2-5

$R_{TH} = 600\ \Omega$

ANSWERS

1. **b**
2. **c**
3. **d**
4. **d**
5. **a**
6. The calculated Thevenin resistance is 2.39 kΩ. A load of 100 kΩ implies the load voltage will be down approximately 2 percent from the ideal open-load or Thevenin voltage. This means the voltmeter reads slightly less than the ideal Thevenin voltage.
7. In Fig. 2-1*a*, a shorted 2.2-kΩ resistor means the voltage between point *A* and common is lower than it should be, which implies a Thevenin voltage that is less than before. Also, the shorted resistor means less Thevenin resistance.
8. In Fig. 2-1*a*, an open 2.2-kΩ resistor implies that all of the source voltage will appear across the *AB* terminals when the load is open. Furthermore, opening the resistor will increase the Thevenin resistance.
9. If I wanted to stay in business, I had better produce batteries with very low internal resistance because batteries are supposed to act like stiff voltage sources for most load resistances.

Experiment 3

TABLE 3-1 TROUBLES AND VOLTAGES

Trouble	V_A	V_B
Circuit OK	5.21 V	1.06 V
R_1 open	0	0
R_2 open	6.9 V	1.41 V
R_3 open	6.81 V	0
R_4 open	6.81 V	6.81 V
R_1 shorted	10 V	2.04 V
R_2 shorted	0	0
R_3 shorted	2.72 V	2.72 V
R_4 shorted	4.92 V	0

ANSWERS

1. **a**
2. **c**
3. **d**
4. **d**
5. **d**
6. **a**
7. **c**
8. **a**
9. **a**
10. **d**

Experiment 4

TABLE 4-1 OHMMETER TESTING

	Expected	Measured 1	Measured 2	Measured 3
R_F	Low	25 Ω	24 Ω	26 Ω
R_R	High	Infinite	Infinite	Infinite

TABLE 4-2 DMM TESTING

	Measured 1	Measured 2	Measured 3
Forward	0.552 V	0.571 V	0.544 V
Reverse	OL	OL	OL

TABLE 4-3 DATA FOR FORWARD BIAS

	Calculated		Measured	
	V_D	V_L	V_D	V_L
Diode 1	0.7 V	9.3 V	0.68 V	9.32 V
Diode 2	0.7 V	9.3 V	0.72 V	9.28 V
Diode 3	0.7 V	9.3 V	0.67 V	9.33 V

TABLE 4-4 DATA FOR REVERSE BIAS

	Calculated		Measured	
	V_D	V_L	V_D	V_L
Diode 1	10 V	0	10 V	0
Diode 2	10 V	0	10 V	0
Diode 3	10 V	0	10 V	0

TABLE 4-5 DIODE CONDUCTION

	D_1	D_2	D_3	D_4
Normal	On	Off	Off	On
Reversed	Off	On	On	Off

TABLE 4-6. DIODE CONDUCTION

	D_1	D_2	D_3	D_4
Normal	On	On	Off	Off
Reversed	Off	Off	On	On

TABLE 4-7 DIODE AND LOAD VOLTAGES

	V_{D1}	V_{D2}	V_{D3}	V_{D4}	V_L
Calculated	0.7 V	0.7 V	9.3 V	9.3 V	8.6 V
Measured	0.68 V	0.72 V	9.32 V	9.28 V	8.6 V

ANSWERS

1. **a**
2. **b**
3. **d**
4. **c**
5. **b**
6. **b**
7. **c**
8. **b**
9. **a**
10. **c**

Experiment 7

TABLE 7-1 HALF-WAVE RECTIFIER

	Calculated	Measured
RMS secondary voltage	12.6 V	15.6 V
Peak output voltage	17.8 V	20 V
DC output voltage	5.67 V	6.6 V
Ripple frequency	60 Hz	60 Hz

TABLE 7-2 FULL-WAVE RECTIFIER

	Calculated	Measured
RMS secondary voltage	12.6 V	15.6 V
Peak output voltage	8.9 V	9.5 V
DC output voltage	5.67 V	6.3 V
Ripple frequency	120 Hz	120 Hz

TABLE 7-3 BRIDGE RECTIFIER

	Calculated	Measured
RMS secondary voltage	12.6 V	15.6 V
Peak output voltage	17.8 V	19 V
DC output voltage	11.3 V	12.5 V
Ripple frequency	120 Hz	120 Hz

TABLE 7-4 TROUBLESHOOTING

	Calculated		Measured	
	V_{dc}	f_{out}	V_{dc}	f_{out}
Diode open	5.67 V	60 Hz	6.25 V	60 Hz
Half-secondary short	5.67 V	120 Hz	5.68 V	120 Hz

TABLE 7-5 CRITICAL THINKING

	Calculated	Measured
RMS secondary voltage	6.3 V	7.73 V
Peak output voltage	8.9 V	8.8 V
DC load voltage	5.67 V	5.53 V
DC load current	21 mA	20 mA
Ripple frequency	120 Hz	120 Hz
Load resistance	270 Ω	267 Ω

ANSWERS

1. d
2. c
3. c
4. c
5. d
6. For a given transformer, the bridge rectifier has the largest unfiltered dc output voltage, ideally 90 percent of the rms secondary voltage versus 45 percent for the others.
7. When any diode opens, the circuit reverts to a half-wave rectifier. For this reason, the unfiltered dc output voltage and the ripple frequency are half of their normal values.
8. If any diode is shorted, the other diode on the same side of the bridge is destroyed and the remaining diodes are unaffected. For instance, if D_1 shorts in Fig. 7-2, D_3 is destroyed because of excessive current. Diodes D_2 and D_4 are unaffected.
9. I used only half the secondary winding to drive the bridge rectifier. This reduced the dc output voltage to approximately 5.67 V. To get approximately 20 mA of dc load current, I selected a load resistance of 270 Ω.

Experiment 8

TABLE 8-1 TRANSFORMER RESISTANCES

$R_{pri} = 33.6\ \Omega$
$R_{sec} = 1.1\ \Omega$

TABLE 8-2 R_L = 1 kΩ AND C = 47 μF

	Calculated	Measured
RMS secondary voltage	12.6 V	15.4 V
Peak output voltage	17.8 V	21.5 V
DC output voltage	17.8 V	19.1 V
DC load current	17.8 mA	19 mA
Ripple frequency	120 Hz	120 Hz
Peak-to-peak ripple	3.16 V	2.5 V

TABLE 8-3 R_L = 1 kΩ AND C = 470 μF

	Calculated	Measured
RMS secondary voltage	12.6 V	15.5 V
Peak output voltage	17.8 V	20 V
DC output voltage	17.8 V	19.9 V
DC load current	17.8 mA	20 mA
Ripple frequency	120 Hz	120 Hz
Peak-to-peak ripple	0.316 V	0.28 V

TABLE 8-4 R_L = 10 kΩ AND C = 470 μF

	Calculated	Measured
RMS secondary voltage	12.6 V	15.6 V
Peak output voltage	17.8 V	20.4 V
DC output voltage	17.8 V	20.4 V
DC load current	1.78 mA	1.99 mA
Ripple frequency	120 Hz	120 Hz
Peak-to-peak ripple	31.6 mV	25 mV

TABLE 14-3 OPTOCOUPLER

V_S	V_{out}
2 V	13.8 V
4 V	13 V
6 V	11.9 V
8 V	10.7 V
10 V	9.6 V
12 V	9 V
14 V	8.7 V

TABLE 14-4 TROUBLESHOOTING

	Estimated V_{LED}	Measured V_{LED}
Open LED	15V	15 V
Shorted LED	0 V	0 V

TABLE 14-5 CRITICAL THINKING

	Calculated			Measured	
	R	I_{LED}	V_{LED}	I_{LED}	V_{LED}
Red LED	680 Ω	19.1 mA	2 V	20.1 mA	1.7 V
Green LED	680 Ω	19.1 mA	2 V	19.6 mA	2 V

ANSWERS

1. **c**
2. **c**
3. **c**
4. **a**
5. **a**
6. When the cathode of a LED is grounded, there is LED current and the LED segment lights up. By grounding one or more cathodes, we can display any digit between 0 and 9. With a LED voltage drop of 2 V, the current through the series resistor is (5 – 2)/270, or 11.1 mA. The LED current in any lit segment equals 11.1 mA/n, where n is the number of lit segments. Therefore, LED brightness decreases as more segments light up.
7. Kirchhoff's voltage law says the voltage across the LED equals the source voltage minus the drop across the series resistor. When the LED is open, there is no drop across the series resistor and the entire source voltage appears across the open LED.
8. I subtracted 2 V (LED drop) from 15 V (source voltage) to get 13 V (voltage across the series resistor). Then I calculated R = 13 V/20 mA, or 650 Ω. The nearest standard sizes are 620 and 680 Ω. Arbitrarily, I selected 680 Ω.
9. By using nine identical resistors, one in series with each cathode. Then the positive supply voltage is connected directly to pin 3. By grounding the lower end of any resistor, we can set up LED current and tight the associated segment.

Experiment 15

TABLE 15-1 TRANSISTOR VOLTAGES AND CURRENTS

Transistor	V_{BE}	V_{CE}	I_B	I_C
1	0.69 V	14.4 V	31.8 μA	6.4 mA
2	0.65 V	14.8 V	31.8 μA	4.8 mA
3	0.75 V	14.2 V	31.8 μA	3.2 mA

TABLE 15-2 CALCULATIONS

Transistor	V_{CB}	I_E	α_{dc}	β_{dc}
1	13.7 V	3.8 mA	0.996	253
2	14.2 V	1.9 mA	0.992	127
3	13.5 V	6.5 mA	0.998	433

TABLE 15-3 TROUBLESHOOTING

Trouble	Estimated V_C	Measured V_C
Open 470 kΩ	+ 15 V	+ 15V
Shorted 1 kΩ	+ 15 V	+ 15V
Open 1 kΩ	0	+ 0.04 V
Shorted collector-emitter	0	0
Open collector-emitter	+ 15V	+ 15 V

TABLE 15-4 CRITICAL THINKING

	R_B	V_C
Calculated	360 kΩ	7.45 V
Measured	370 kΩ	7.76 V

ANSWERS

1. **c**
2. **b**
3. **d**
4. **c**
5. **a**
6. The V_{BE} drop was close to 0.7 V for all three transistors. It was also apparent that collector current is much greater than base current. My weakest transistor had a β_{dc} of 197, which means collector current was approximately 200 times greater than base current.
7. I measured the full supply voltage, + 15 V. With the base resistor open, the transistor goes into cutoff and operates at the lower end of the dc load line, which has a collector voltage of + 15 V. Stated another way, there was no collector current, which means no voltage drop across the collector resistor. Therefore, the full supply voltage appeared at the collector.
8. A shorted transistor has either zero ohms or a very low value of resistance because of internal damage. Because of this, the voltage across a very low resistance approaches zero.
9. Answers will vary.
10. Because the base current and the beta current set the current.

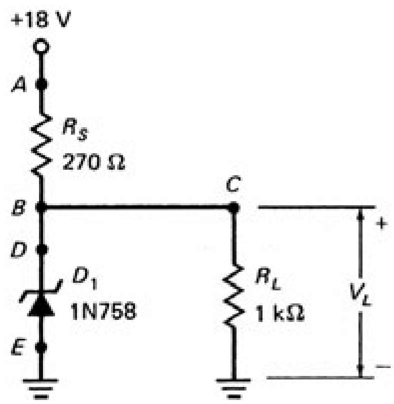
Experiment 16

TABLE 16-1 FIRST CIRCUIT

	V_{BE}	V_{CE}	Region
Calculated	0.7 V	6.04 V	Active
Measured	0.72 V	6.97 V	Active

TABLE 16-2 SECOND CIRCUIT

	V_{BE}	V_{CE}	Region
Calculated	0.7 V	0 V	Saturation
Measured	0.75 V	0.1 V	Saturation

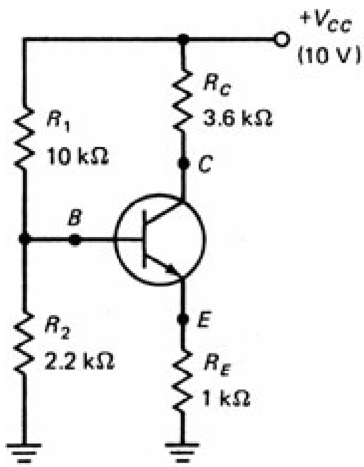


	1	2	3	4	5	6	7
A	14.2	OK	10.5	0	18	14.2	OK
B	18	0	OK	14.2	0	10.5	18
C	0	18	14.2	∞	10.3	0	14.2
D	18	14.2	OK	18	OK	OK	18
E	OK	18	14.2	0	14.2	10.3	0
F	10.3	0	0	0	18	0	10
G	18	0	10.5	14.2	0	18	OK

MEASUREMENTS

OK	*T*1	*T*2	*T*3	*T*4	*T*5	*T*6	*T*7	*T*8
V_A : *C*2	V_A : *D*7	V_A : *A*5	V_A : *D*1	V_A : *E*2	V_A : *B*2	V_A : *B*1	V_A : *B*7	V_A : *G*6
V_B : *F*1	V_B : *F*4	V_B : *B*4	V_B : *A*6	V_B : *D*4	V_B : *C*6	V_B : *A*3	V_B : *C*3	V_B : *A*4
V_C : *C*5	V_C : *C*1	V_C : *E*3	V_C : *G*4	V_C : *F*5	V_C : *B*5	V_C : *B*6	V_C : *C*7	V_C : *F*3
V_D : *E*6	V_D : *F*2	V_D : *F*2	V_D : *D*2	V_D : *G*1	V_D : *F*6	V_D : *G*3	V_D : *E*5	V_D : *G*2
D_1 : *A*7	D_1 : *B*3	D_1 : *A*2	D_1 : *C*4	D_1 : *C*4	D_1 : *G*7	D_1 : *E*1	D_1 : *D*6	D_1 : *E*7

Figure 5-44



	1	2	3	4	5	6	7
A	10	1.1	2.7	1.1	0	0.7	0
B	0	1.8	∞	2.1	OK	10	1.83
C	0.5	0	1.13	7	3.4	1.13	OK
D	9.3	OK	1.8	1.1	10	10	1.1
E	0	2.1	8	4	0.4	OK	3
F	1.83	10	9.4	0	10	6	2.1
G	2.1	2.8	0.4	2.9	1.5	0.1	0

MEASUREMENTS

OK	*T*1	*T*2	*T*3	*T*4	*T*5	*T*6
V_B: *B*2	V_B: *D*5	V_B: *A*6	V_B: *D*3	V_B: *E*2	V_B: *F*4	V_B: *C*5
V_E: *D*7	V_E: *D*1	V_E: *C*2	V_E: *D*7	V_E: *F*7	V_E: *A*5	V_E: *A*3
V_C: *F*6	V_C: *F*3	V_C: *G*6	V_C: *A*1	V_C: *B*4	V_C: *B*6	V_C: *G*2
R_2: *D*2	R_2: *E*6	R_2: *D*2	R_2: *B*5	R_2: *C*7	R_2: *D*2	R_2: *B*3

*T*7	*T*8	*T*9	*T*10	*T*11	*T*12
V_B: *F*1	V_B: *B*1	V_B: *D*4	V_B: *A*2	V_B: *A*5	V_B: *F*1
V_E: *C*6	V_E: *C*2	V_E: *E*5	V_E: *E*5	V_E: *F*4	V_E: *C*2
V_C: *B*6	V_C: *D*5	V_C: *C*1	V_C: *D*5	V_C: *C*2	V_C: *D*6
R_2: *E*6	R_2: *A*5	R_2: *D*2	R_2: *D*2	R_2: *D*2	R_2: *B*5

Figure 8-30

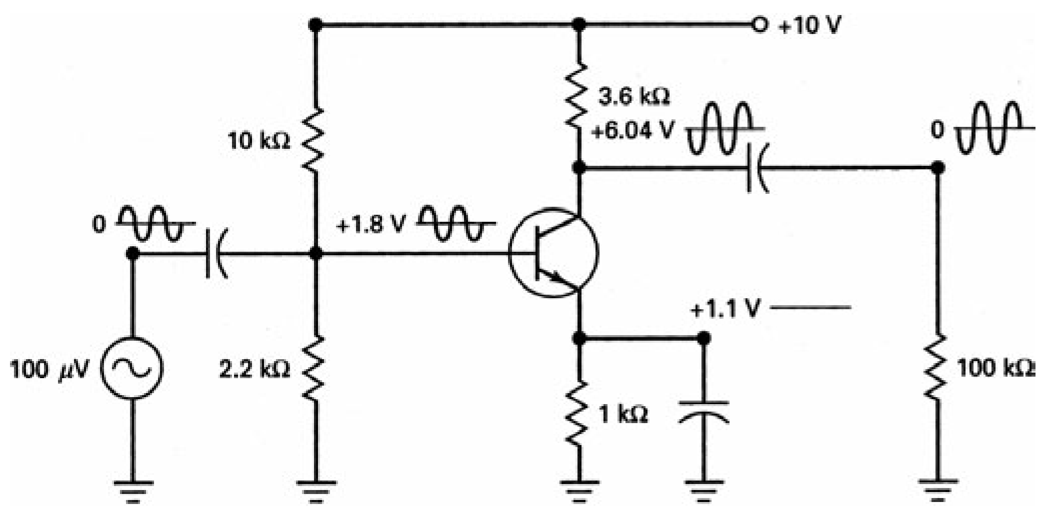


Figure 9-8

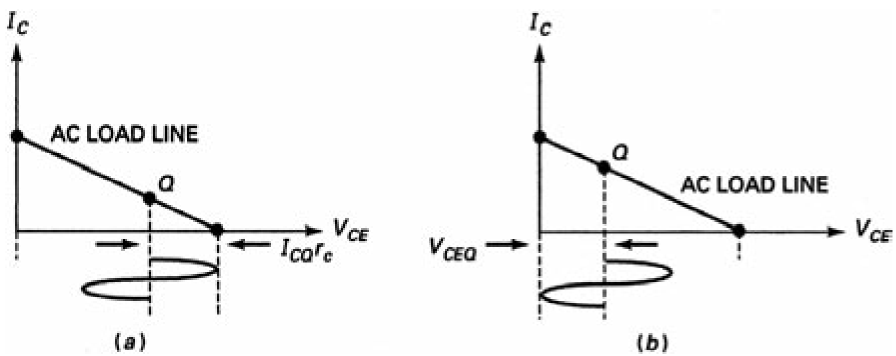


Figure 12-6

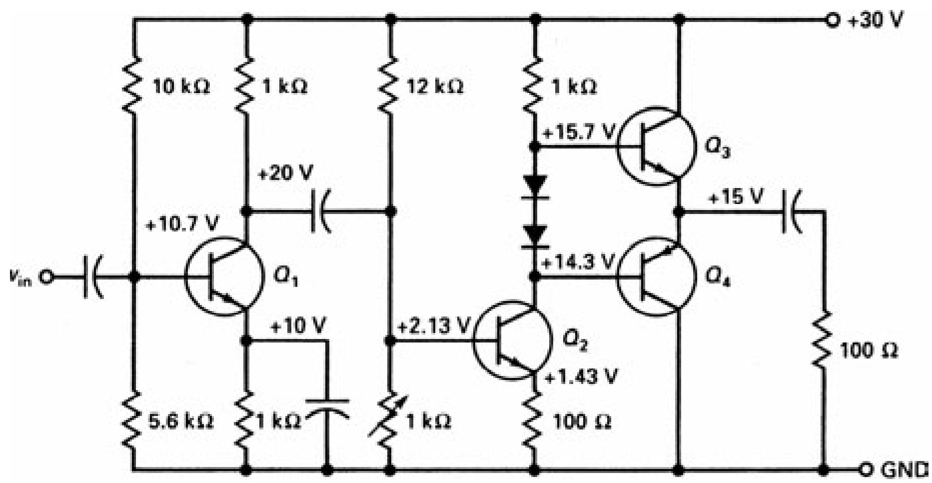
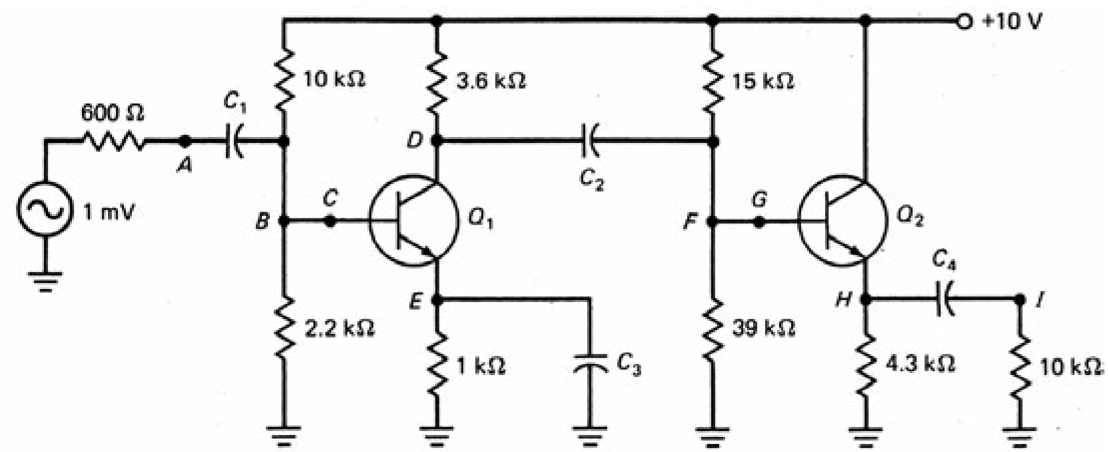

+30 V
10 kΩ
1 kΩ
12 kΩ
1 kΩ
+15.7 V
Q_3
+20 V
+15 V
+10.7 V
v_{in}
Q_1
+14.3 V
Q_4
+10 V
+2.13 V
Q_2
100 Ω
+1.43 V
5.6 kΩ
1 kΩ
1 kΩ
100 Ω
GND

Figure 12-43



	OK	T1	T2	T3	T4	T5	T6	T7
v_A	B2	A2	G7	A3	C2	E7	B2	C5
v_B	G7	C5	C5	A7	A1	B5	C1	A2
v_C	D4	D4	B7	D3	E7	E2	B7	C1
v_D	C6	D2	B3	E2	C3	C7	A4	B3
v_E	D5	B4	E2	F4	B5	B6	E2	A7
v_F	A6	C6	D2	G2	C3	E5	C7	D7
v_G	F5	G1	B6	B6	B1	B4	D3	B3
v_H	B3	A6	A7	G6	E4	A7	A7	D3
v_I	G1	E2	B4	B4	A5	F4	D5	G2

	1	2	3	4	5	6	7
A	0.75	0.6	1	95	2	70	0
B	2	0.6	70	0	0.75	0	0.6
C	0.6	0.75	2	50	0.6	70	0
D	95	70	0	0.6	0	32	70
E	0.75	0	14	2	0	70	0.75
F	95	95	70	0	70	19	3
G	70	0	39	2	28	0	0.6

MILLIVOLTS

Figure 11-30

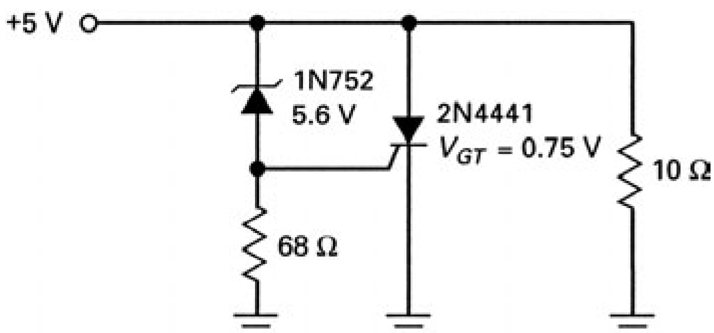
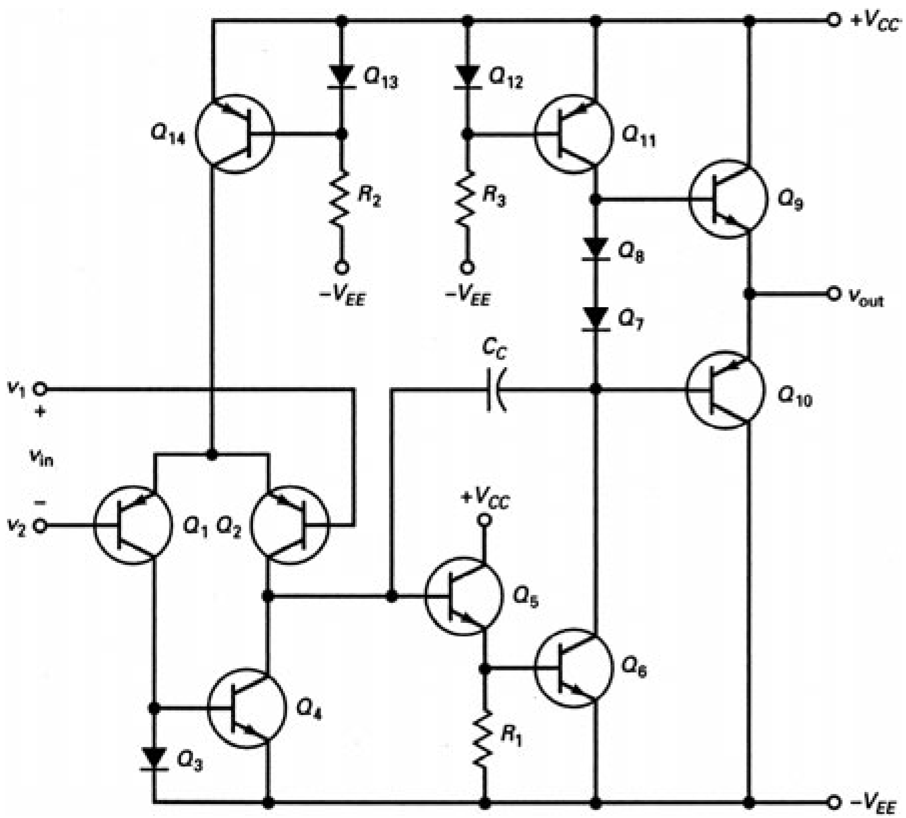


Figure 15-21



$+V_{CC}$
Q_{13}
Q_{12}
Q_{14}
Q_{11}
R_2
R_3
Q_9
Q_8
$-V_{EE}$
$-V_{EE}$
v_{out}
Q_7
C_C
v_1
+
Q_{10}
v_{in}
−
$+V_{CC}$
v_2
Q_1 Q_2
Q_5
Q_6
Q_4
R_1
Q_3
$-V_{EE}$

Figure 18-4

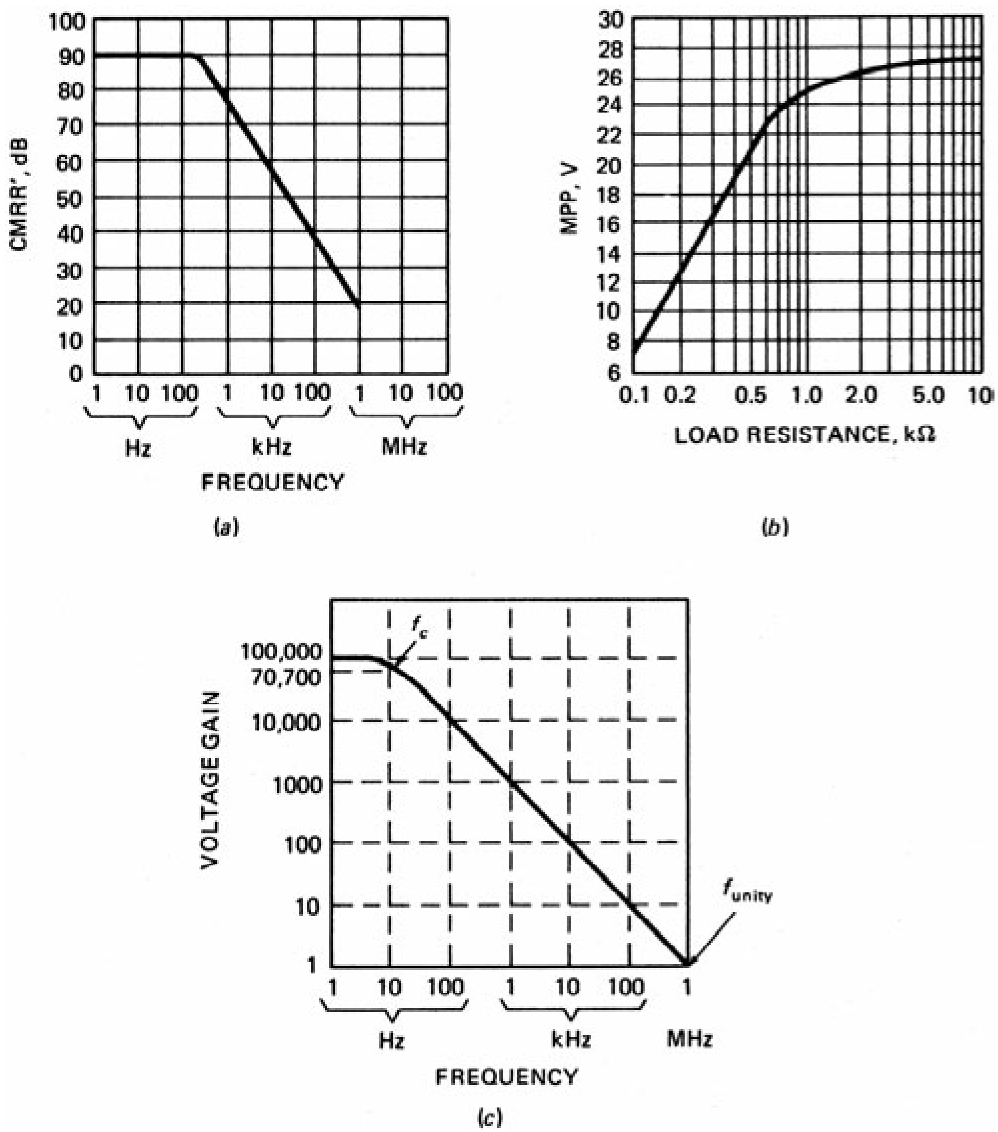

CMRR', dB
100
90
80
70
60
50
40
30
20
10
0
1 10 100 1 10 100 1 10 100
Hz
kHz
MHz
FREQUENCY
(a)
MPP, V
30
28
26
24
22
20
18
16
14
12
10
8
6
0.1 0.2 0.5 1.0 2.0 5.0 10
LOAD RESISTANCE, kΩ
(b)
VOLTAGE GAIN
100,000
70,700
10,000
1000
100
10
1
f_c
f_{unity}
1 10 100 1 10 100 1
Hz
kHz
MHz
FREQUENCY
(c)

Figure 18-7

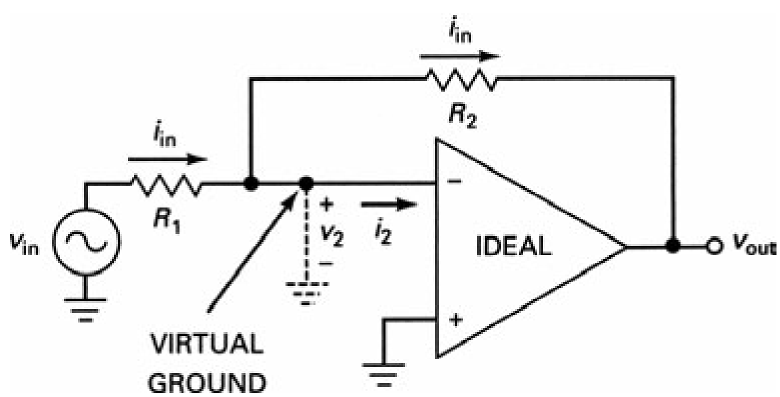
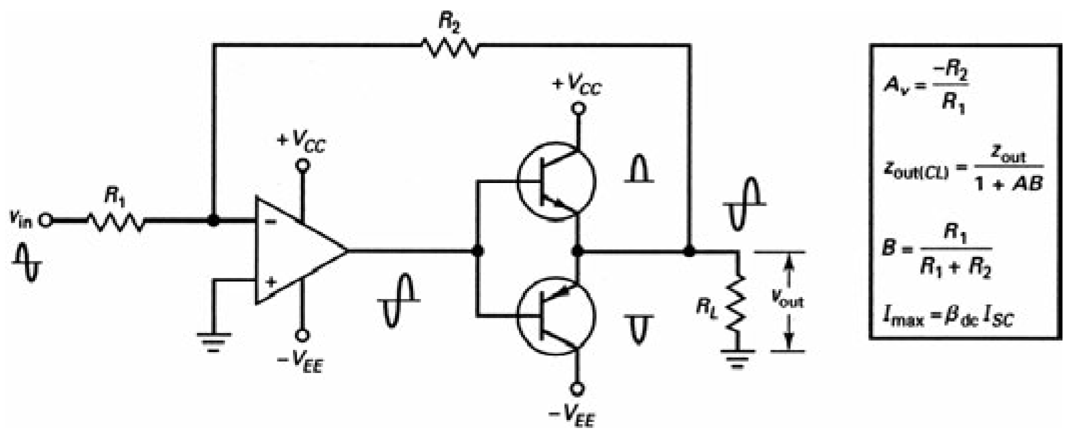
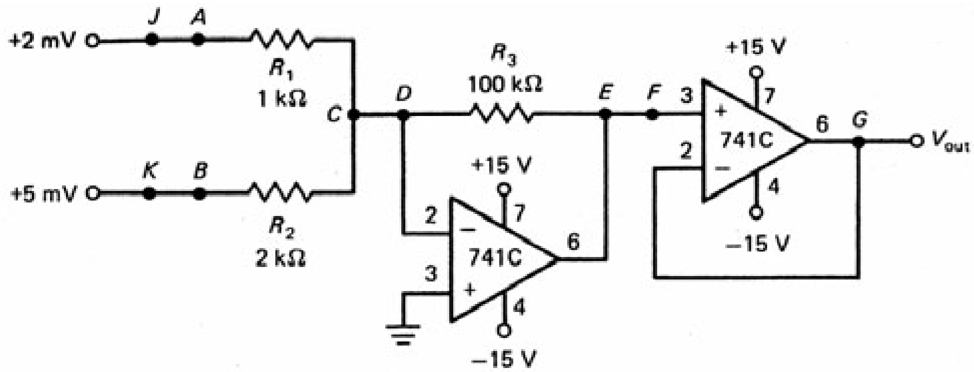


Figure 18-13



R_2
$+V_{CC}$
$+V_{CC}$
v_{in}
R_1
$-V_{EE}$
$-V_{EE}$
R_L
v_{out}
$A_v = \frac{-R_2}{R_1}$
$z_{out(CL)} = \frac{z_{out}}{1 + AB}$
$B = \frac{R_1}{R_1 + R_2}$
$I_{max} = \beta_{dc} I_{SC}$

Figure 20-27

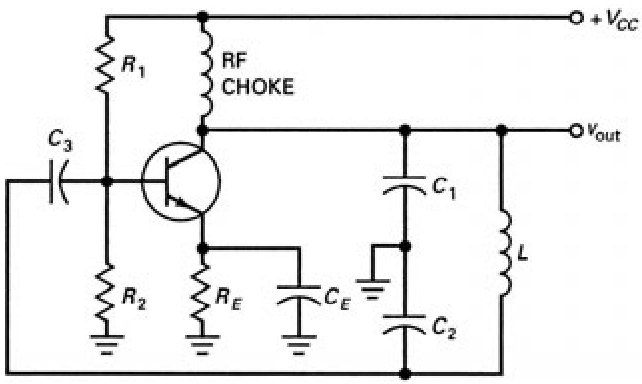


	OK	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
V_A	G2	D1	H4	G3	C5	D8	G4	C4	E5	G7	H6
V_B	D6	H3	A4	D6	C3	G5	F1	D2	B3	H8	C8
V_C	A8	E7	D4	A6	B2	H7	B2	F5	E6	D4	A1
V_D	C3	A8	C1	C5	A8	F2	C1	B6	C1	A8	E4
V_E	A2	F4	F7	G1	D3	C1	H5	A3	G6	F2	F3
V_F	F4	E6	B5	D7	B5	E6	E3	B8	H1	G4	A5
V_G	C7	F2	D3	F6	F7	B7	F8	C2	F8	D4	B1

	1	2	3	4	5	6	7	8
A	5	450	−13.5 V	5	−13.5 V	2	5	0
B	−13.5 V	0	5	3	200	3	0	−13.5 V
C	0	−13.5 V	0	2	2	3	450	5
D	2	5	200	0	3	5	−13.5 V	2
E	450	3	250	5	2	0	0	5
F	5	0	−13.5 V	450	3	−13.5 V	200	250
G	−13.5 V	2	2	0	5	250	2	2
H	250	450	5	2	250	2	3	5

MILLIVOLTS UNLESS OTHERWISE INDICATED

Figure 20-45



$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

$$C = \frac{C_1C_2}{C_1 + C_2}$$

$$B = \frac{C_1}{C_2}$$

$$A_{v(min)} = \frac{C_2}{C_1}$$

Figure 23-15